UNIVERSIDAD PONTIFICIA COMILLAS

ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA (ICAI)

OFFICIAL MASTER'S DEGREE IN THE ELECTRIC POWER INDUSTRY

Master's Thesis

ANALYSIS OF THE IMBALANCE BETWEEN GENERATION AND SCHEDULE - CHILE

Author: **Mª Ángeles Díaz Garrido**

Supervisor: **Manuel Fernández Serrano**

Co- Supervisor: **José Salmerón Berdejo**

Madrid, July 2015

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Abstract

The imbalance between generation and schedule generates problems to the electric systems as it introduces some difficulties in the management of the system and increases the cost supported by agents and consumers.

One of the main objectives of the liberalized systems is to be cost-efficient by reducing the avoidable costs. These objectives are especially relevant when it comes to an essential commodity such as electricity.

For this purpose it is important to bear in mind the most relevant aspects to control the imbalance cost. It is especially important when a significant integration of renewable energy is desired as they, especially wind and photovoltaic, account for the most important levels of imbalances.

The present study aims to look for the best way to reduce the imbalance costs caused by renewable generation. This work will focus on the Chilean electricity market where there is a considerable development of renewable generation capacity and there is no regulation regarding the units' imbalance. The imbalance cost reduction will become more important as the share of renewables increase in the energy mix.

Additionally, the key regulatory aspects in order to increase efficiency and reduce the cost of the electric systems through imbalance cost reduction are detailed in this work.

Resumen

El desvío entre la energía programada y energía generada introduce una serie de problemas en los sistemas eléctricos al hacerlos más difícil de gestionar y aumentar los costes que deben de ser pagados por los agentes y los consumidores finales.

Uno de los principales objetivos de los sistemas eléctricos liberalizados es conseguir la mayor eficiencia posible y reducir los costes innecesarios al máximo. Esto cobra especial relevancia cuando se trata de artículos de primera necesidad como es el caso de la electricidad.

Por este motivo es importante tener muy presente los aspectos más importantes para contener el coste de los desvíos especialmente cuando se quiere integrar niveles relevantes de energías renovables ya que tecnologías como la eólica o la solar son las que tienen los niveles más importantes en cuanto a costes de desvíos se refiere.

La presente tesis busca encontrar la forma de reducir al máximo este coste y para ello analiza el caso del mercado Chileno donde se está introduciendo una cantidad reseñable de renovables sin tener regulación destinada a contener el nivel de desvíos y motivar a los agentes a no tener desvío.

Además, se detallan los aspectos regulatorios más importante que se deberían tener en cuenta a la hora de aumentar la eficiencia y reducir el coste de los sistemas eléctricos a través de una reducción en el coste del desvío que cada vez cobrará más importancia según se introduzca más nivel de energía renovable no gestionable.

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CHAPTER 1

INTRODUCTION

1.1 Motivation

Wind to Market is a company that operates in the Spanish electricity market managing the sale of the energy of non-conventional generators, mainly renewables, in the wholesale energy market.

Wind to Markets offers to their costumers market services such as 24 x 7 operation desk, energy sale settlement, metering claims, real-time monitoring, etc. but one of the main advantage for its customers that sell energy in the wholesale market through a company as Wind to Market is the reduction in the cost of the imbalance between generation and schedule because of the market aggregator effect. That imbalance cost saving could result in dozens of thousands of euros per year for a single medium-sized installation. It is therefore a valuable service especially for renewables electricity generators for whom it is impossible to foresee the actual production with accuracy; this means that there is always a high production uncertainty, which increases the probability of bearing a high imbalance cost.

Renewables are playing a key role in reducing the CO_2 emissions. Thus, there is a trend all around the world towards increasing the level of renewable capacity. The more integrated renewable energy the more difficult the operation becomes, as the average imbalance of the system increases and the system security may be at stake. The Economic Theory states that one of the best ways to lower a cost to the minimum is to allocate it to those who cause the imbalance, so they will be incentivized to do their best in order to achieve its reduction. So it may happen with imbalance cost. Also a lesser imbalance in the market will allow new renewable capacity to go on-line, maximizing the renewable integration in the electricity system.

In this sense, Wind to Market is interested in knowing the way the imbalance is managed in other electricity markets such as Chile where renewables are starting to play an important role and where the way of allocating the imbalance cost is quite different.

Moreover, this analysis could be useful as Wind to Market may find more efficient ways for an electric system to manage the imbalance and a potential business development.

Hence to reduce the imbalance cost it is important to send the right signals to all market agents in order to make them perform in the most efficient way. We want to analyze if the current way of managing the imbalance between generation and schedule in Chile is efficient or it may be improved.

1.2 Objectives

The main objective of the thesis is to find the most important aspects in order to efficiently manage the imbalance between generation and schedule in an electric system.

The Chilean electric system will be reviewed as renewables are increasingly becoming more relevant and they will have to deal with significant amount of imbalances soon. So far they do not seem to have implemented any imbalance cost allocation other than allocating the cost to consumers that could have fostered imbalance reduction in the short term. Henceforth, the effect of lack of efficient regulation in this market will be examined.

We also have secondary objectives, listed below, as question to be answered in the different sections of the thesis:

- Is the Chilean electric system efficient at managing imbalance between generation and schedule?
- How much could the imbalance be reduced?
- How much money could be saved by reducing the imbalance?
- What are the key aspects in order to manage efficiently the imbalance in an electric system?

1.3 Structure of the report

The thesis is divided in 5 parts. It starts with a brief introduction where the motivation and objectives are explained.

The second part is an introduction to Chilean market in order to identify the most important aspects of the Chilean market and the imbalance settlements processes.

In the third section the imbalance for wind and photovoltaic units are presented and compared with imbalance levels in the power system in Spain, as it counts with a mature renewable sector, so as to estimate how much Chilean imbalance could be reduced.

Once the level of imbalance has been shown and the potential reduction is known, the potential saving in monetary terms are estimated in chapter four.

In the fifth chapter, the most important aspects in regulation to have a good level of imbalance for avoiding unnecessary costs are explained.

To end with, we present a summary of the findings, an explanation of the limitations in the study and a proposal of additional research that could be done.

CHAPTER 2

THE CHILEAN ELECTRICITY MARKET

2.1 Main features

In the 80's, the liberalization and the unbundling of activities (generation, transmission and distribution) arrived to the Chilean electricity market. It was the first country in the world that liberalized the electricity sector. Since then, the generation is developed under competition conditions but the Government still has a substantial regulatory role.

The Chilean electricity system consists of four interconnected subsystems:

- Northern Interconnected System (hereinafter referred as SING): It is a major system and supplies the northern zone. Its generation is mainly thermal focus on the mining industry.
- Central Interconnected System (hereinafter referred as SIC): It is also a major system and supplies the central zone. It is the biggest system in terms of installed capacity and electricity supply.
- Aysén: It is made up of five medium-size systems (Palena, Hornopirén, Carrera, Cochamó and Aysén) and represents 0.4% of Chile's installed capacity.
- Magallanes: It is made up by four medium-size systems (Punta Arenas, Puerto Natales, Porvenir and Puerto Williams) and represents 0.6% of Chile's installed capacity.

The study is going to focus on the two major systems as they account for 99% of the installed capacity.

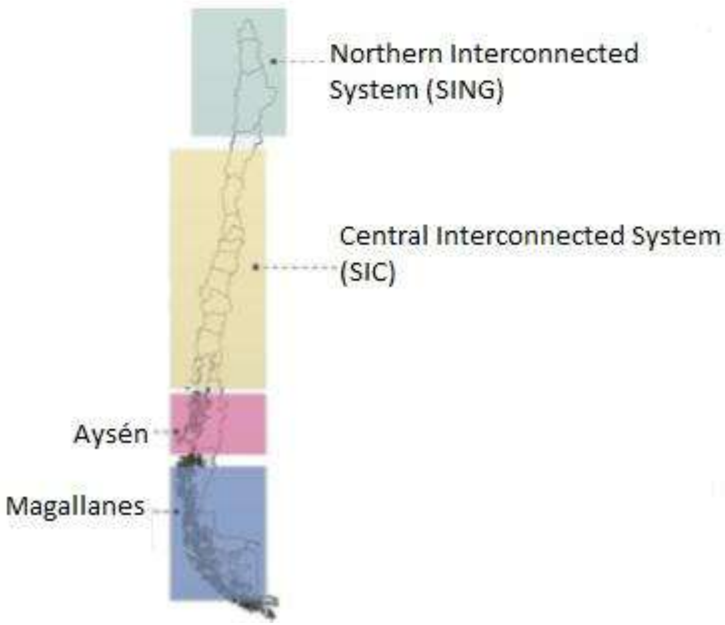

Figure 1: Power systems in Chile.
Source: [Campo, 2013]

2.1.1 Institutional framework

The main institutions are the following:

- ***National Energy Commission*** (hereinafter referred to as CNE): It is an autonomous and decentralized state organization with ministerial rank and its main functions are:
  - To elaborate and coordinate plans for the good performance and development of the sector
  - To advice the Government.
- ***Superintendency of Electricity and Fuels*** (hereinafter referred to as SEC): It is in charge of supervising the safety, quality and price in the operation of electricity, gas and fuel services.
- ***National Environmental Commission*** (hereinafter referred to as CONAMA): its aims are ensure that citizen can live in a pollution-free environment, to protect the environment and to preserve the nature. It must propose environmental policies to the President of the Republic.
- ***Panel of Experts of the General Law of Electricity Services***: it is an entity with limited powers, in charge of solving conflicts with electricity legislation and disagreement between companies of the electricity sector. It made up of seven members with long and wide professional or academic experience.
- ***Economic Load Dispatch Centers*** (hereinafter referred to as CEDEC) they are private organizations that coordinate the operation of the system and their main functions are:
  - Keeping the electricity system security.
  - Guaranteeing the most economic operation for the generation units.
  - Ensuring open access to the transmission system.
  - Establishing the Energy Marginal Cost and the economic transaction between agents.

  There is a CDEC for each mayor system: CEDEC-SIC and CDEC-SING. The members of a CDEC are the companies which own generation and transmission facilities and non-regulated customers connected to transmissions facilities with some exceptions.

Figure 2 shows the institutional framework of the electricity sector.

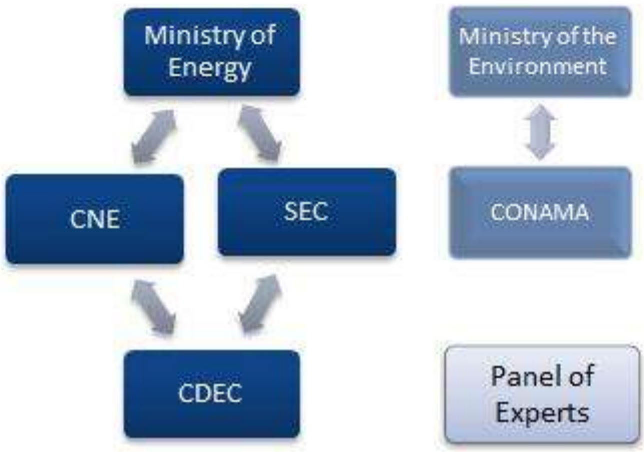

Figure 2: Institutional framework.
Source: own production, data from [Palma, 2009] & [Van de Wyngard, 2013]

2.1.2 Installed capacity, generation and ownership

In December 2014, Chilean systems had an installed capacity hereinafter laid down:

- Central Interconnected System (SIC): 15,151 MW.
- Northern Interconnected System (SING): 4,076 MW (92% of thermal origin from fossil fuels such us coal, gas and oil).

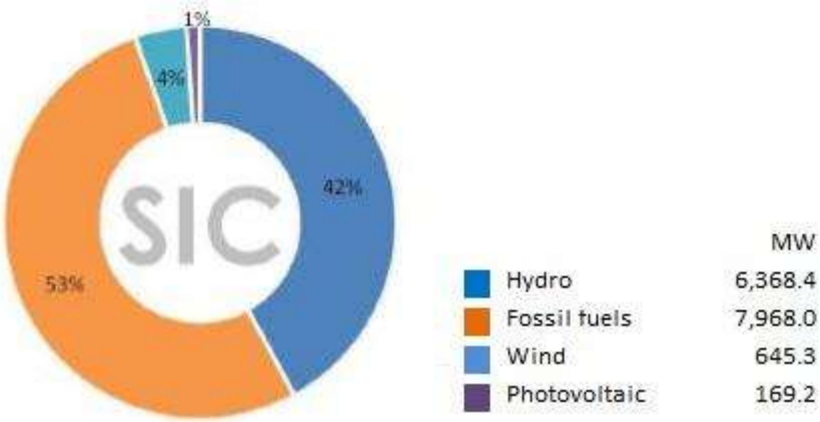

Figure 3: Installed capacity (SIC).
Source: own production, data from [Valgesta, 2015]

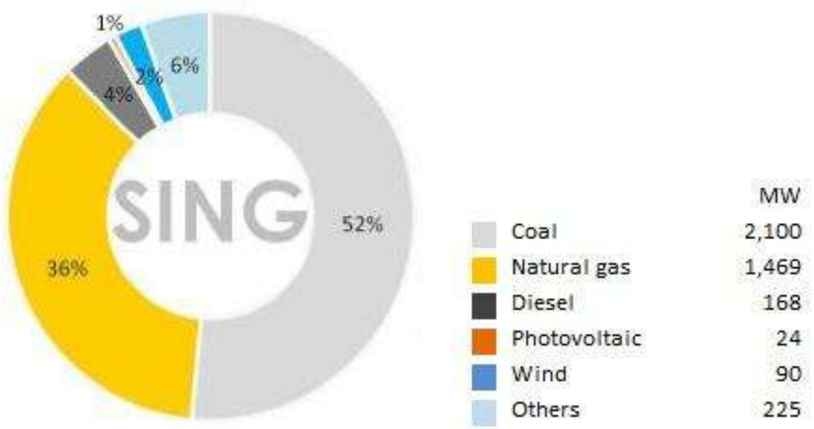

Figure 4: Installed capacity.(SING)
Source: own production, data from [Valgesta, 2015]

The gross energy generation for 2014 by system and technology is shown in the table 1and the figure 5 gives the generation of the two major systems together by technology.

Gross electricity generation 2014	SIC [GWh]	SING [GWh]	TOTAL
Thermal	27,204	17,316	44,520
Hydro	23,448	79	23,527
Wind	1,211	215	1,426
Solar	371	90	461
TOTAL	**52,234**	**17,701**	**69,934**

Table 1: Gross energy generation by technology and system.
Source: own production, data from [Generadoras, 2014].

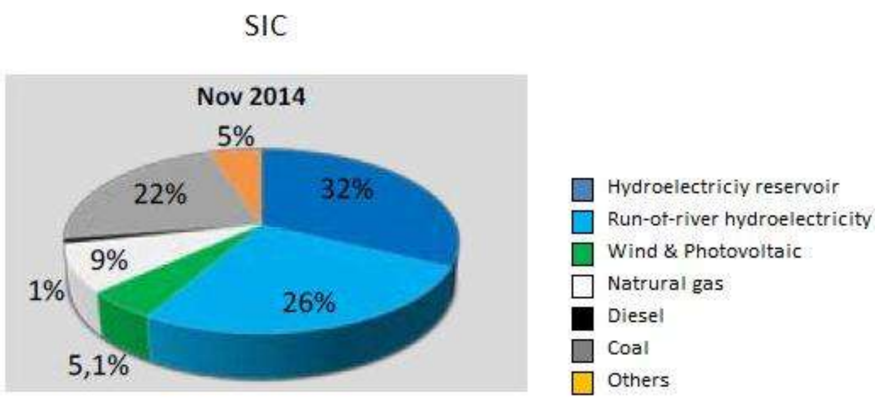

Figure 5: Energy generation by technology (SIC).
Source: own production, data from [Systep 2014].

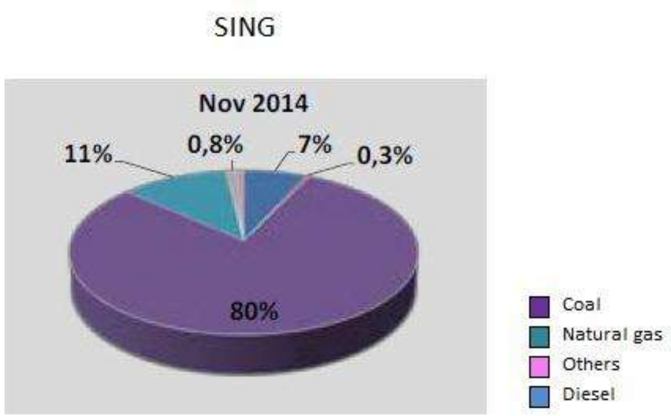

Figure 6: Energy generation by technology (SING).
Source: own production, data from [Systep 2014].

There is a quite high concentration of the ownership of the generation units as table 2 shows.

Just seven companies account for 80% of the energy produced on SIC and only five companies for 85% of the energy of SING.

Companies 2014	SIC		SING	
	Gross generation [GWh]	Participation [%]	Gross generation [GWh]	Participation [%]
Colbún	1,063	24%		
Endesa	753	17%		
AES Gener	677	15%		
Guacolda	398	9%		
Pehuenche	324	7%		
San Isidro	313	7%		
Sociedad Eléctrica de Santiago	84	2%		
E-CL			633	42%
Angamos			369	24%
Norgener			120	8%
Andina			76	5%
Celta			90	6%
TOTAL	**3,612**	**81%**	**1,288**	**85%**

Table 2: Generation companies.
Source: own production, data from [Generadoras, 2014].

2.1.3 Maximum and minimum demand.

The maximum and minimum demand of 2014 is shown for each major system in table 3:

Demand 2014	SIC [MW]	SING [MW]
Maximum	7,547.3	2,329.4
Minimum	3,748.6	114.8

Table 3: Maximum and minimum demand 2014.
Source: own production, data from [Generadoras, 2014].

The graphs 7 and 8 represent the peak (red line) and the low (blue line) monthly demand over the last thirteen months.

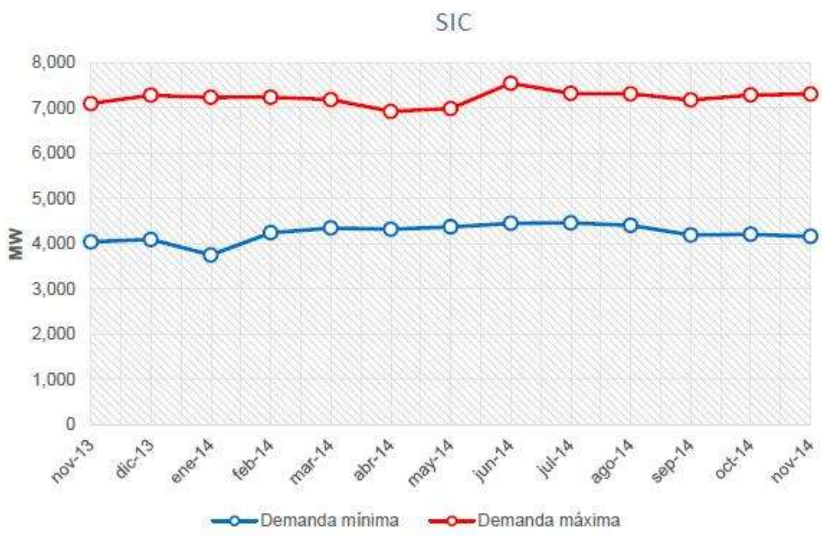

Figure 7: Maximum and minimum monthly demand 2014 - SIC.
Source: [Generadoras, 2014].

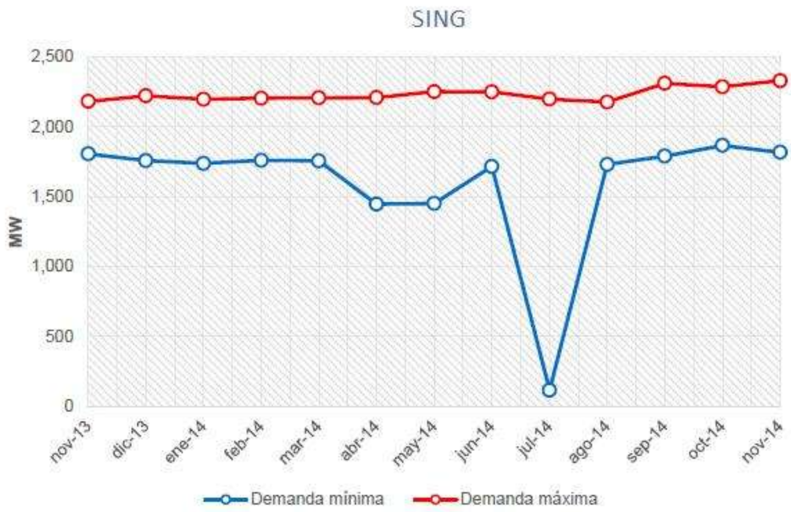

Figure 8: Maximum and minimum monthly demand 2014 - SING.
Source: [Generadoras, 2014].

The low demand plummeted for SING in July 2014 to just 114.8 MW due to a problem in the transmission system making it necessary to perform a load shedding, cutting off 1,711.5 MW of consumption. Apart from that event, peak and low demand levels usually remain quite stable.

2.1.4 Renewables

According to the Law 20.257, there is an obligation of producing 5% of the total energy using renewable sources. The figure 6 shows the renewable generation from November 2013 to November 2014 by technology and the compulsory level according to law 20.257 (red line). We can see as the renewable generation is significantly higher than that of the Law states.

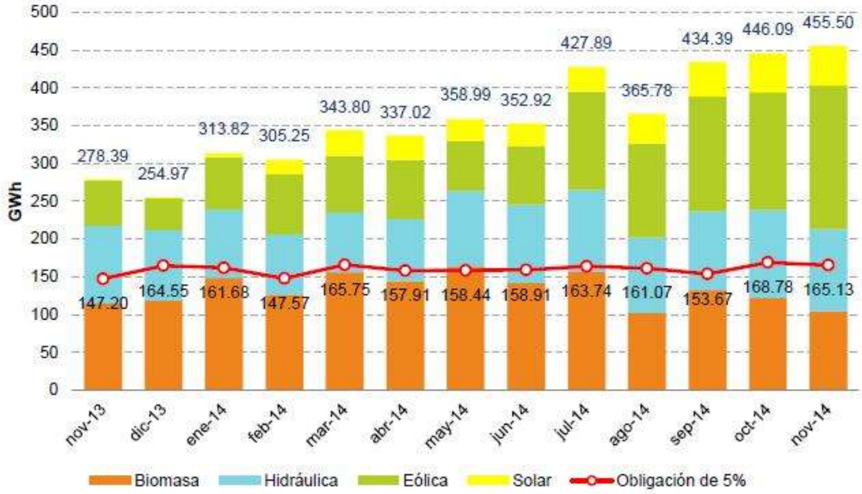

Figure 9: Renewable Energy November 2013 to November 2014.
Source: [Generadoras, 2014].

As we will see later in the document, the work will focused on the photovoltaic and wind units, especially in the larger system (SIC) as it counts with the more robust data.

The tables 4 show the facilities which imbalances will be analyzed:

SIC		SING	
WIND UNITS	SOLAR UNITS	WIND UNITS	SOLAR UNITS
Eólica Canela 1	Solar Tambo Real	Eólica Valle de los Vientos	María Elena FV
Eólica Canela 2	Solar SDGx01		Pozo Almonte Solar 2
Eólica Lebu	Solar Esperanza		Pozo Almonte Solar 3
Eólica Totoral	Solar Llano de Llampos		Solar El Águila I
Eólica Monte Redondo	Solar San Andrés		Solar La Huayca 2
Eólica Ucuquer	Solar Santa Cecilia		
Eólica Ucuquer 2	Solar Techos de Altamira		
Eólica Talinay	Solar Diego de Almagro		
Eólica Punta Colorada	Solar PSF Pama		
Eólica Cuel	Solar PSF Lomas Coloradas		
Eólica El Arrayán	Solar Las Terrazas		
Eólica San Pedro	Solar PV Salvador		
Eólica Los Cururos	Solar Chañares		
Eólica Punta Palmeras			
Eólica Taltal			

Table 4: Wind and solar facilities 2014.
Source: own production, data from: [CDEC SIC] & [CDEC SING].

2.1.5 Variable Cost and Price

There are three important concepts regarding costs and pricing in the Chilean Electric Market hereinafter listed:

1. Marginal costs: it is the variable cost of the more expensive unit operating in the system in a certain hour. As a reference, it is used the variable cost of the Quillota bar, in SIC, and Crucero, in SING, as they are the load center of the systems.

2. Average market price: it is the mean price of the contract that the generation companies report to the National Energy Commission for the sales in a period of four months. The period considered in a publication is the four month period ending three months before the publication.
3. Nodal price: it is computed by the CNE using an indicative expansion plan and estimating the marginal cost for the next 48 months.

The graphs in the figures 10 and 11 reflect the costs and prices evolution for the two major systems:

Figure 10: Evolution of SIC prices.
Source: [Generadoras, 2014].

Figure 11: Evolution of SING prices.
Source: [Generadoras, 2014].

In the next section it will be commented further on these references prices and what they are used for.

2.1.6 Generation project

The Chilean Energy Market is still growing and the regulation in the sector is strongly supporting the renewable energy. There were 123 projects waiting for approval to be developed by the end of 2014, out of which 77 were wind and photovoltaic ones.

Table 5 and 6 provide the solar and wind projects waiting to be installed by technology and system:

WIND PROJECTS	SYSTEM	Capacity [MW]
Ampliación III Parque Eólico Lebu - Cristoro	SIC	11
Parque Eólico Los Olmos	SIC	142
Parque Eólico San Gabriel	SIC	201
Parque Eólico Mulchén	SIC	89
Parque Eólico Campo Lindo	SIC	145
Parque Eólico Los Buenos Aires	SIC	40
Parque Eólico Mesamávida	SIC	103
Parque Eólico Malleco	SIC	270
Parque Eólico La Flor	SIC	30
PARQUE EÓLICO NEGRETE	SIC	36
Parque Eólico Tchamma	SIC	
PARQUE EOLICO CHILOE	SIC	101
Ampliación II Parque Eólico Lebu - Cristoro	SIC	9
Proyecto Parque Eólico Aurora	SIC	192
Parque Eólico Cateo	SIC	100
Parque Eólico Lebu Etapa III	SIC	184
TOLPÁN	SIC	306
PICHIHUÉ	SIC	118
KÜREF	SIC	61
Parque Eólico Cerro Tigre	SING	264
ANDES WIND PARKS	SING	65
Parque Eólico Sierra Gorda Este	SING	168
WIND PROJECTS		2,635

Table 5: Wind projects.
Source: own production, data from: [Generadoras, 2014].

PHOTOVOLTAIC PROJECTS	SYSTEM	Capacity [MW]
Parque Solar Olmué	SIC	126
DOMEYKO SOLAR	SIC	14
Proyecto Campos del Sol Norte	SIC	186
Proyecto Campos del Sol Centro	SIC	237
Parque Solar Llano Victoria	SIC	27
Proyecto Solar Escondido	SIC	245
Proyecto Parque Solar Limache	SIC	9
Central Solar Fotovoltaica Illapel	SIC	48
Planta Solar Fotovoltaica Piedra Colgada	SIC	90
Planta Solar Fotovoltaica Domeyko	SIC	60
Planta Solar fotovoltaica Doña Carmen	SIC	40
Proyecto Parque Solar Las Luces	SIC	24
Proyecto Parque Solar Aguas Blancas 2	SIC	72
Parque Solar Fotovoltaico DAS2	SIC	55
Parque Solar Pedernales	SIC	63
Parque Fotovoltaico La Huella	SIC	60
Parque Fotovoltaico Lagunillas-El Olivo	SIC	40
Parque Fotovoltaico, Planta Cerro Blanco	SIC	20
Proyecto Campos del Sol Sur	SIC	698
Proyecto Fotovoltaico El Pelícano	SIC	101
Proyecto Fotovoltaico Llanta	SIC	112
Proyecto Fotovoltaico Sierra Soleada	SIC	49
DIA Divisadero	SIC	114
NUEVA PLANTA FOTOVOLTAICA CARRERA PINTO SOLAR	SIC	90
Parque Solar Abasol	SIC	62
Parque Solar Punta del Viento	SIC	47
PLANTA FOTOVOLTAICA SOLAR 9 Y LINEA DE TRANSMISION 110 kV	SIC	50
Proyecto Fotovoltaico Sol de Varas	SIC	101
Proyecto Solar Toro	SIC	56
SOLAIREDIRECT GENERACION CARRERA PINTO	SIC	47
PLANTA FOTOVOLTAICA CARDONES SOLAR I	SIC	35
Parque Solar Los Aromos	SIC	81
PARQUE SOLAR BARTOLILLO	SIC	9
Proyecto Guanaco Solar	SIC	50
Planta FV El Salado II	SIC	36
Proyecto Fotovoltaico Sol de Atacama	SIC	81
Proyecto Solar Conejo	SIC	306
Central Fotovoltaica Inca de Varas I	SIC	50
DIEGO DE ALMAGRO	SIC	52
Parque Solar Fotovoltaico Sol de Tarapacá	SING	150
MODIFICACIÓN PARQUE SOLAR AZAPA	SING	104
Planta Fotovoltaica San Pedro V	SING	39
Espejo de Tarapacá	SING	300
Parque Solar Fotovoltaico Sol del Desierto	SING	369
PROYECTO FOTOVOLTAICO LAGUNAS	SING	63
AMPLIACIÓN PLANTA FOTOVOLTAICA DIEGO DE ALMAGRO SOLAR	SING	29
Proyecto Parque Fotovoltaico	SING	28
PLANTA SOLAR PINTADOS	SING	77
Proyecto Fotovoltaico Azabache	SING	77
Pampa Solar	SING	120
Kalisaya	SING	88
Parque Fotovoltaico Capricornio	SING	90
Proyecto Fotovoltaico Los Manolos	SING	80
Parque Fotovoltaico Gramadal	SING	92
Alfa Solar	SING	280
PHOTOVOLTAIC PROJECTS		5,627

Table 6: Photovoltaic projects.
Source: own production, data from: [Generadoras, 2014].

2.2 Operation of the Chilean market and financial settlement

As mentioned above, the Chilean Market has been liberalized for more than 25 years. Ever since the generation activity has been developed under competition conditions and distribution and transmission networks have remained regulated activities as they are natural monopolies.

In the generation activity there is a competitive system based on marginal cost pricing (peak load pricing), where consumers pay a price for the energy and a price for the capacity associated to peak demand hours.

This system ensures that the income from energy sales (valued at marginal cost) and income from capacity sales (valued at developing peak power) will cover the investment and operation costs of the generation units needed to match the demand in the short term as it is shown in figure 9.

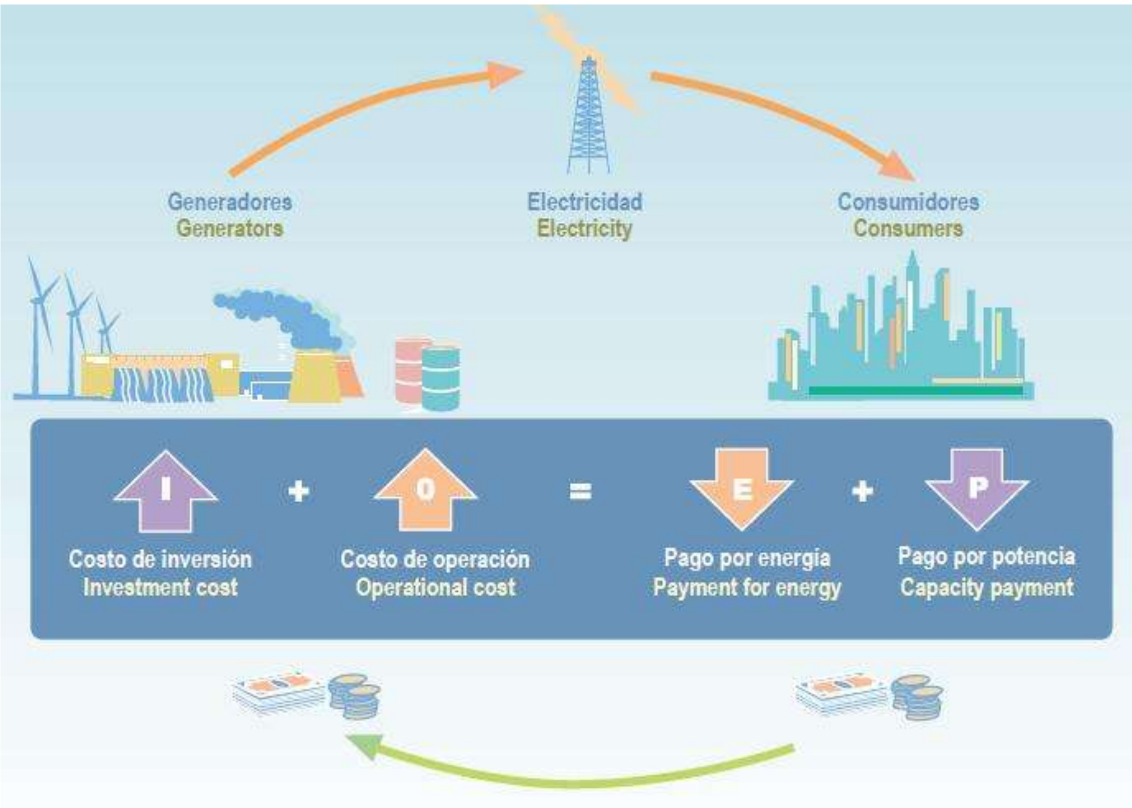

Figure 12: Financial balance in the marginal model.
Source: [Palma, 2009]

The wholesale market in Chile is formed by a compulsory spot market (pool-type structure) and financial bilateral contracts as shows figure 10:

Figure 13: Chilean Wholesale Market.
Source: [Palma, 2009]

There are no physical bilateral **contracts** in the Chilean market, they just have financial nature and the CDECs are in charge of the hourly physical dispatch.

The generation companies can sale the energy by means of contracting with non-regulated customers (capacity greater than 2 MW) at freely agreed price and with distribution companies. When the energy is sold to the distribution companies the following price structure is applied:

1. Nodal price for contract formalized before law 20018 was applicable.
2. Price defined through a regulated process of supply tenders for contract under Law 20018.

Distribution companies sell the electricity to the regulated costumer applying the regulated tariffs and to the non-regulated customers that do not want to buy energy from generation companies.

The Figure 11 shows the different kinds of contracts and the applicable prices in each case.

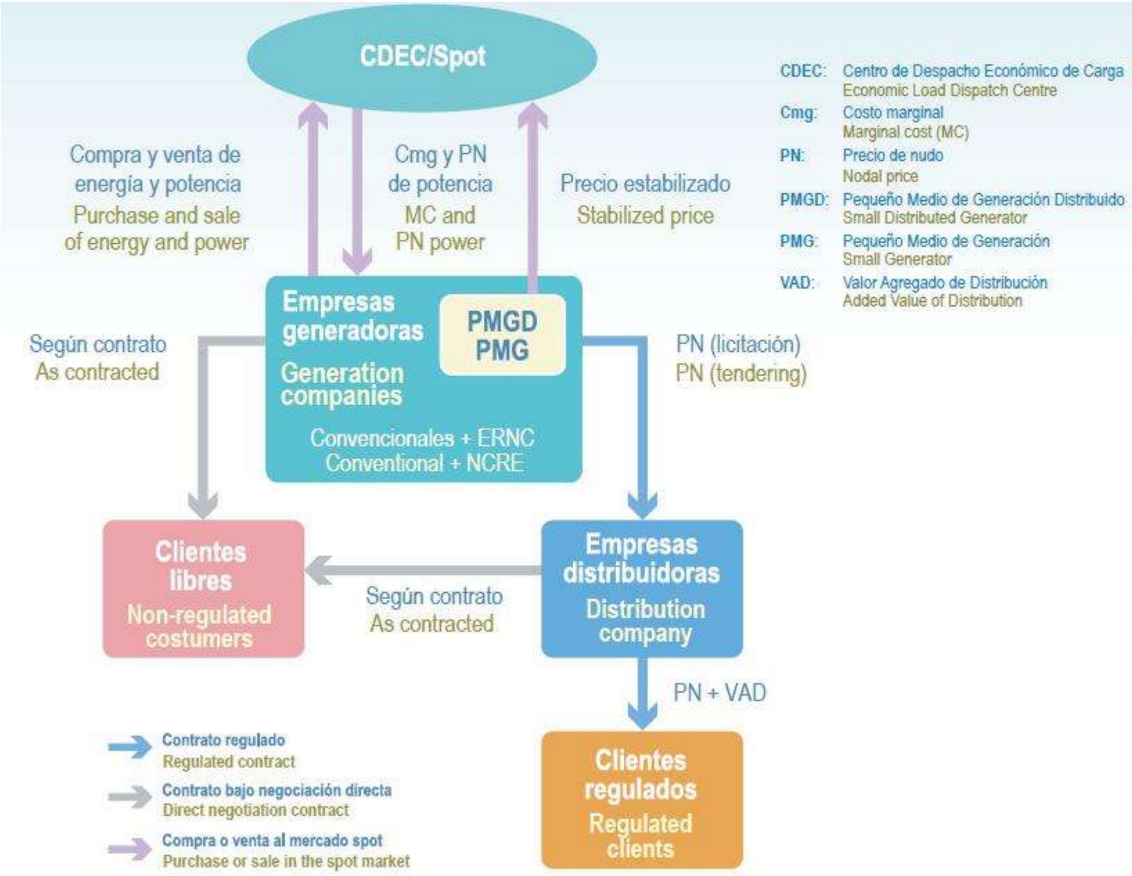

Figure 14: Electricity Market Remuneration.
Source: [Palma, 2009]

The **pool** sets the short-term prices as a result of a centralized economic dispatch carried out by CDEC. The dispatch is based on the variable operational cost reported by the generation units (which can be audited) in order to obtain the system hourly dispatch.

This prices are also applicable for the non-conventional renewable energy but, it also can be used a nodal price for energy sales for small generators (hereinafter referred as PMG) and small distributed generator (hereinafter referred as PMGD).

- PMGD: generation units connected to distribution networks and capacity surplus lower or equal than 9 MW.
- PMG: generation units connected to sub-transmission networks and capacity surplus lower or equal than 9 MW.

The spot market is formed by generation companies. Generation companies sell and buy energy between them to adjust the energy sold throughout financial contracts to the energy committed in the economic dispatch. The energy is settled at hourly Marginal Cost by the CDEC.

It is planned to change the remuneration of the ancillary services although it is still under study. Meanwhile, any injection due to safeguarding the security of the system, supply or demand imbalance, network congestions, etc. is valued at the difference between the variable cost of the generation unit that starts to produce to solve the problem and the marginal price of the node where energy is generated. Currently, there is no compensation for the opportunity cost when a company that have been scheduled is not finally producing to solve an imbalance.

To sum up, we may identify the following steps in the financial settlement of the Chilean Market:

1. ***Generators sell energy through contract*** to non-regulated customers and distribution companies.
2. The ***CDECs operate and program the electric system*** according to the minimum operation cost criterion but taking into account the regulation regarding the security and quality of services.
3. ***Generators sell and buy in the spot market*** in order to adjust contract position to the program given by the CDEC as a result of the hourly dispatch.
4. In general, ***CDECs values the injection and withdrawal*** of electricity, taking into account the energy sold throughout financial contracts, at Marginal Price of the busbar or node where electricity is generated or consumed. PMG and PMGD can sell the energy at nodal price.
5. ***Injections due to security system, supply or demand imbalance, network congestions, etc. are valued*** at the difference between the variable cost of the generation unit that starts to produce to solve the problem and the marginal price of the node where energy is generated.

CHAPTER 3

ANALYSIS OF THE IMBALANCE

Hereafter it is going to be analysed the imbalance between generation and schedule in the Chilean market where generators do not have any incentive to comply with the programs set by the CDEC. It is going to be revised if this lack of motivation results in a big amount of imbalance that consequently causes some unnecessary cost for the system due to the excessive use of ancillary services. When there is an imbalance, a unit is producing more or less electricity than it was supposed to according to the CDEC schedules, while another unit has to start or stop to produce energy through the processes of the ancillary services, turning out as an additional cost.

This chapter analyse this effect in energy terms and compare it with the situation in the Spanish electricity system, thus it will show if imbalance levels in Chile are in a normal range.

In the following section it will be made the same analysis but in monetary terms in order to see how big this extra cost can be or in other words, how much money could be saved with some regulatory measures that may incentive market participants to reduce their imbalance.

The analysis of this chapter is going to be focused on the two major systems but more deeply in the biggest system (SIC) as it offers more detailed information. Also, we are going to focus our study on wind and solar units as they are the technologies that cause the more relevant amount of imbalance.

3.1 Methodology used in order to compute the imbalance between generation and schedule in the Chilean market.

This first section of the chapter is going to be dedicated to explaining the methodology used in order to compute the hourly imbalance of the Chilean wind and photovoltaic units for 2014.

As it was pointed out before, we were able to make a **<u>deeper analysis in the SIC</u>** system, following this process:

1. Hourly information about generation [CDEC SIC OP] and schedule [CDEC SIC PR] for wind and solar units was downloaded from the CDEC website.
2. The data was organized by month using an Excel macro (see code in the ANNEX 1) and then It was compared the hourly generation and schedule for each unit, set the results in absolute values and added by months and technology to compute the ***monthly absolute net imbalance by technology*** according to (1):

$$\text{Absolute net monthly imblance}^{\text{tech}} = \sum_{h=1}^{M} \left| \sum_{i=1}^{N} \text{Generation}_h^{\text{tech,i}} - \text{Schedule}_h^{\text{tech,i}} \right| \quad \textbf{(1)}$$

3. Finally, the ***monthly percentage of imbalance with respect to schedule*** is computed dividing $Absolute\ net\ imblance_{m}^{tech}$ *(1)* by the sum of monthly Schedule such as it is reflected in (2):

$$\text{Monthly Percentage of Imbalance}^{\text{tech}} = \frac{\text{Absolute net monthly imblance}^{\text{tech}}}{\sum_{h=1}^{M}\sum_{i=1}^{N} \text{Schedule}_h^{\text{tech,i}}} \, (\mathbf{2})$$

Where:

Tech: the technology (wind or solar) for which different terms are computed
M: total amount of hours of the month
N: total amount of facilities of the tech technology
$\mathbf{Generation_h^{tech,i}}$**:** actual production in MWh of the *i* facility of *tech* technology in the *h* hour

$\mathbf{Schedule_h^{tech,i}}$ **:** scheduled program in MWh of the *i* facility of *tech t*echnology in the *h* hour

3.2 The imbalance level in the Chilean market.

After following the steps listed above we obtain the number shown in tables 7 and 8 and graphs in the figures 15 and 16:

CDEC SIC	WIND			
	Absolute hourly net imbalance (MWh)	Schedule (MWh)	Generation (MWh)	% OF IMBALANCE RESPECT TO SCHEDULE
January	30,009	43,398	57,157	69.15%
February	29,030	56,725	63,674	51.18%
March	33,352	57,601	59,648	57.90%
April	32,446	59,801	62,409	54.26%
May	28,058	37,072	53,256	75.69%
June	29,416	44,926	59,457	65.48%
July	25,288	49,111	55,771	51.49%
August	31,979	53,433	58,016	59.85%
September	27,920	53,497	64,378	52.19%
Octuber	28,573	58,271	70,259	49.04%
November	31,853	74,690	95,004	42.65%
December	39,796	74,787	92,451	53.21%
AVERAGE 2014				**56.84%**

Table 7: Wind imbalance SIC 2014.
Source: own production, data from [CDEC SIC].

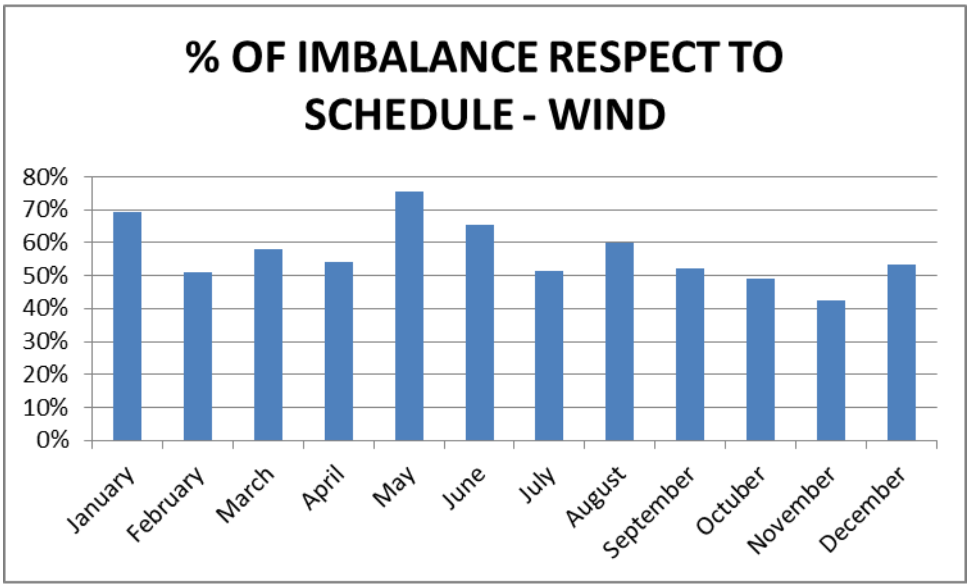

Figure 15: Percentage of imbalance respect to schedule - wind.
Source: own production, data from [CDEC SIC].

CDEC SIC	PHOTOVOLTAIC			
	Absolute hourly net imbalance (MWh)	Schedule (MWh)	Generation (MWh)	% OF IMBALANCE RESPECT TO SCHEDULE
January	3,604	638	4,310	564.83%
February	15,454	684	17,834	2259.42%
March	26,739	1,301	31,156	2055.26%
April	23,224	1,256	27,388	1849.02%
May	6,060	25,250	21,649	24.00%
June	3,355	21,458	23,019	15.63%
July	3,483	24,171	26,151	14.41%
August	4,528	29,363	32,107	15.42%
September	6,388	34,106	37,366	18.73%
Octuber	5,558	39,889	43,695	13.93%
November	7,039	38,943	43,382	18.08%
December	10,844	47,604	57,218	22.78%
AVERAGE 2014				**572.63%**

Table 8: Photovoltaic imbalance SIC 2014.
Source: own production, data from [CDEC SIC].

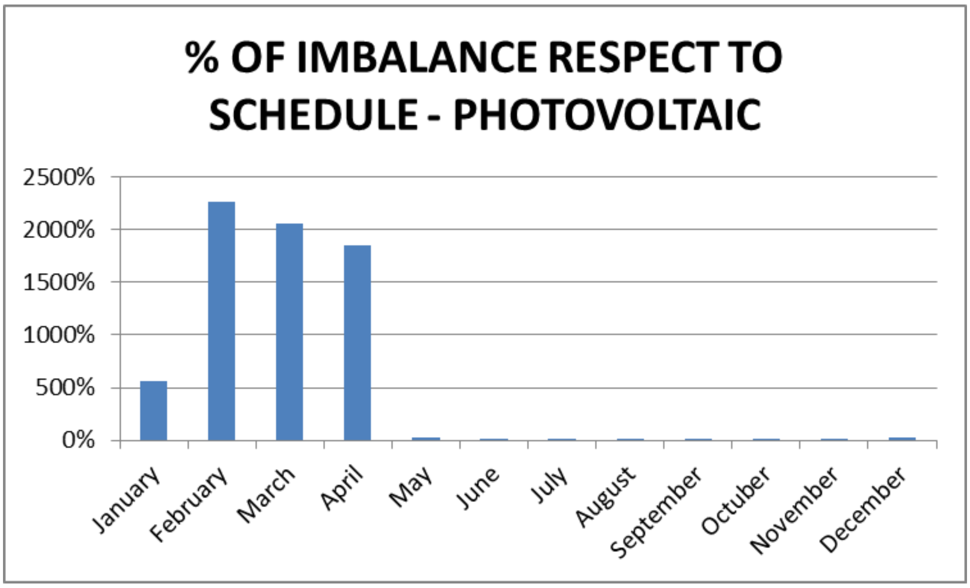

Figure 16: Percentage of imbalance respect to schedule - photovoltaic.
Source: own production, data from [CDEC SIC].

As seen in Table 7, the imbalance for ***wind units*** was more stable and it ranged between 42% and 75% with respect to schedule.

The overall monthly generation was greater than the monthly schedule mainly because some new units started to produce after commissioning without scheduling in the economic dispatch.

The difference between generation and imbalance was especially high in the following months:

- January (69.1% of imbalance over schedule): there was one unit that was producing but it had not been scheduled (Negrete), though this fact provoked 6,889.4 MWh of imbalance (16% of the total wind imbalance for January). Also, there was another unit (Talinay) whose absolute imbalance represented 29 % of the total imbalance for all the wind units in January 2015. In this case, there was not any pattern in the imbalance, half of the imbalance was because its generation exceeded its schedule and the other half because greater program. Also, there were two units (Canela 2 and Monte Redondo) whose absolute imbalance represented 15 % of the total imbalance, each one of them. In this cases, both units had more generation than program committed (around 70% of the imbalance was positive in both cases).
- May (75.7% of imbalance respect to schedule): they were two units (El Arrayán and San Pedro) that did not have any program scheduled but they were producing and therefore causing an imbalance which amounted to 24% of the total imbalance of the wind units. Also, Talinay and Negreta again had remarkable levels of imbalance, 22% and 16% of the total wind imbalance respectively.
- June (65.5% of imbalance respect to schedule): El Arrayán and San Pedro still had no got any program scheduled but they were again producing, therefore they accounted for 24% of the wind imbalance as in the month before. The imbalance of Talinay and Negrete (23% and 13% respectively) stood out again.

From the analysis of the imbalance from wind units it can be concluded:

- There was a remarkable percentage of the imbalance caused by units that had not been scheduled but they were generating electricity. It is important to pay attention to these cases in order to reduce the imbalance and thus the cost involved.
- In addition to the above mentioned there were units with big imbalance without an imbalance pattern. In other words, it seems that these imbalances were not caused by faults. Then, it can be assumed that they were, in part, caused by careless practise probably due to lack of motivation to updating the best generation forecast possible.

Regarding to ***photovoltaic units***, there was a clear improvement from May but imbalance has continued to be quite high.

At the beginning of the year there were two generation sites that account for more than 90% of the imbalance. Llano de Llampos and Solar San Andrés had not energy committed but they generated electricity, resulting in a huge amount of imbalance.

The imbalances for the rest of the examined period remained quite stable between 14.4% and 24% but, as it will be seen in the next sections, it was still too high.

The imbalance was lower from May to December because there were not facilities without schedule and, at the same time, producing significant amount of energy.

It may be seen in the tables 7 and 8 that monthly generation constantly exceeded the schedule (just in the case of May for photovoltaic units the schedule was higher than generation). In every month there were at least two units without schedule while generating electricity, such as Llano de LLampos that stared to produce 17th of January but it had not any energy scheduled until June.

Nevertheless the hourly negative imbalance cannot be ignored (production below schedule) as it reached more than 250,000 MWh (35% over the total imbalance).

As regards **SING analysis**, as it was already mentioned, there was not robust hourly data so the aggregated monthly values for generation and energy schedule were the only data that it could be analysed. Therefore this analysis is not good enough to get credible conclusions, as it is not really reflecting the quantity of imbalance, but it is probably a good enough proxy to verifying if there are some similarities to the SIC subsystem.

In the table 9 has been collected the aggregated monthly values by technology just mentioned.

CDEC SING	WIND	
	Schedule (MWh)	Generation (MWh)
January	-	11,366
February	15,436	15,661
March	7,901	14,641
April	16,822	14,419
May	17,676	17,530
June	13,857	18,009
July	17,220	18,556
August	19,982	18,736
September	19,701	20,878
October	18,905	20,371
November	21,565	22,119
December	22,621	24,231

CDEC SING	PHOTOVOLTAIC	
	Schedule (MWh)	Generation (MWh)
January	-	556
February	-	775
March	849	1,389
April	3,002	4,157
May	4,968	6,042
June	4,476	6,288
July	4,577	6,704
August	5,002	7,246
September	5,274	7,657
October	4,980	7,431
November	6,625	12,565
December	7,041	29,758

Table 9: Wind and photovoltaic imbalance SING 2014.
Source: own production, data from [CDEC SING COM].

In spite of the absence of hourly data the following conclusions were found by just comparing the aggregate values per month:

- There was no schedule for wind and solar units in January and in the case of solar units, they still had no any schedule in February. Consequently, it seems that there was a problem with the schedule of new units as it happened in SIC.
- There was a month for each technology (highlighted in red) where the generation doubled the schedule and, the generation for solar units in December were more than four times higher than schedule.
- In the case of solar technology, it can be appreciated that schedule was always lower than generation as it happened in SIC.

From the findings of this analysis we can figure out that some of the problems regarding to imbalance seems to be similar in the two major systems of Chile, Central Interconnected System and Northern Interconnected System.

3.3 The imbalance level in the Spanish market.

In order to be able to estimate how much the Chilean imbalance could be reduced, Spanish imbalance was examined and compared with the Chilean imbalance because it may be considered as a mature renewable market where there is much more control and regulation, in terms of imbalance, than in Chile.

By comparing both systems it was intended to see the difference in the imbalance in a system where there is an incentive to be balanced with another system where there is not such inducement.

Tables 10 and 11 show the values of the monthly imbalance published by Red Eléctrica de España, System Operator in Spain, for the year 2014 and by technology. There is more detailed information about data used in Annex 2.

REE	WIND			
	Absolute hourly net imbalance (MWh)	Schedule (MWh)	Generation (MWh)	% OF IMBALANCE RESPECT TO SCHEDULE
January	460,996	6,370,988	6,539,485	7.24%
February	456,576	5,628,987	5,884,285	8.11%
March	431,555	4,878,096	5,050,331	8.85%
April	353,036	3,908,282	3,950,218	9.03%
May	336,345	4,104,434	4,134,841	8.19%
June	315,645	3,177,059	3,275,488	9.94%
July	274,747	3,583,459	3,589,983	7.67%
August	302,870	2,844,707	2,856,686	10.65%
September	256,732	2,068,051	2,131,312	12.41%
October	319,958	3,546,455	3,382,663	9.02%
November	341,759	5,225,093	5,066,189	6.54%
December	280,019	4,784,907	4,760,610	5.85%
AVERAGE 2014				**8.62%**

Table 10: Wind imbalance REE 2014.
Source: own production, data from [REE].

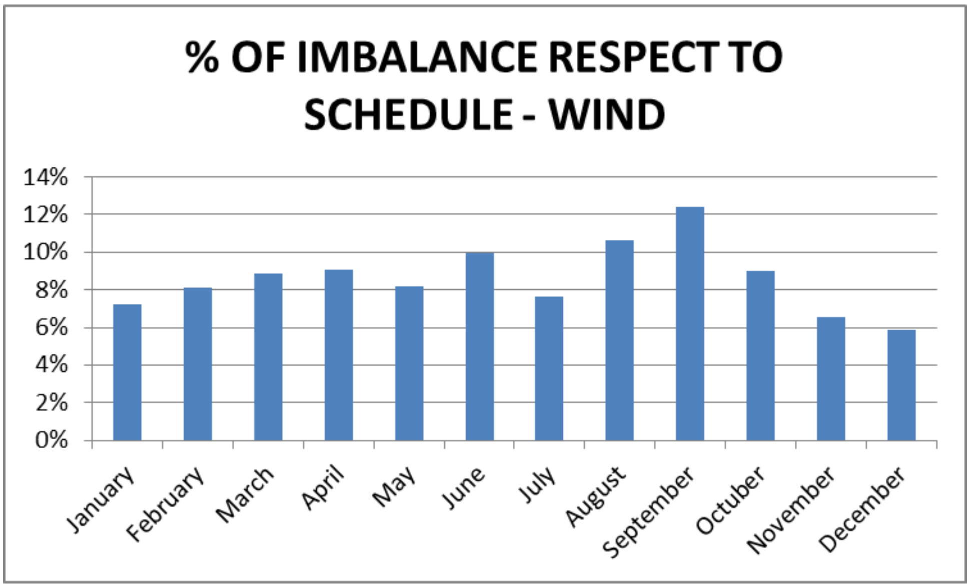

Figure 17: Percentage of imbalance respect to schedule - wind.
Source: own production, data from [REE].

REE	PHOTOVOLTAIC			
	Absolute hourly net imbalance (MWh)	Schedule (MWh)	Generation (MWh)	% OF IMBALANCE RESPECT TO SCHEDULE
January	70,126	402,856	352,691	17.41%
February	66,704	431,246	405,785	15.47%
March	66,603	699,284	697,630	9.52%
April	61,697	765,308	753,264	8.06%
May	54,046	889,022	882,487	6.08%
June	53,518	877,941	862,010	6.10%
July	53,416	928,878	908,592	5.75%
August	45,070	868,470	870,343	5.19%
September	60,257	693,511	653,339	8.69%
Octuber	57,517	613,785	613,998	9.37%
November	57,785	394,068	360,917	14.66%
December	59,460	450,432	430,253	13.20%
AVERAGE 2014				**9.96%**

Table 11: Photovoltaic imbalance REE 2014.
Source: own production, data from [REE].

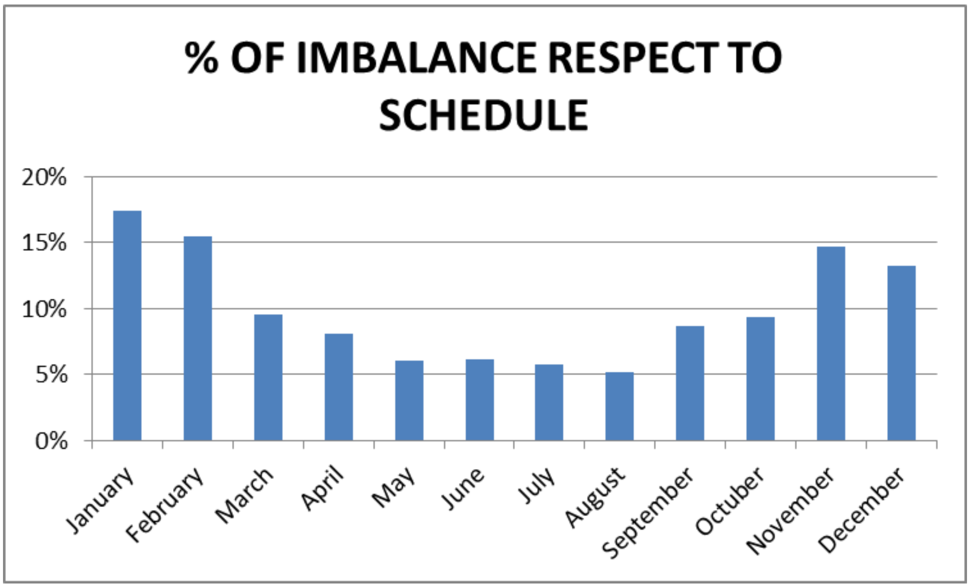

Figure 18: Percentage of imbalance respect to schedule - photovoltaic.
Source: own production, data from [REE].

In the tables 10 and 11 it can be seen the same information that tables 7 and 8 showed in the previous section but in this case for the Spanish system.

It can be observed that imbalance is more stable in Spain. They vary between 5.9% and 12.4% with an average imbalance of 8.6% in the case of wind. Imbalances spanned from 5.2% to 17.4% with an average imbalance of 10% in the case of solar.

Also, it can be established the seasonal effect due to the change in the production. The imbalance, in case of wind, was higher in the months of August and July when the lower productions levels were registered. This effect is due to the power curve (P-m/s curve) of the wind turbine, this curve shows a strong gradient at low wind speeds, which are common in summer; during the winter high wind speeds imply stable output active power. On the contrary, the higher imbalances levels, in the case of photovoltaic, were registered in January, February, November and December when solar radiation was lower.

3.4 Comparative and results.

We find big differences between the imbalances in Spain and the ones in Chile when we compare the data from the two previous sections.

In order to better analyze them, the information have been compiled and summarized in tables 13 and 14 and the graphs in figures 19 and 20:

WIND	% of imbalance respect to schedule - **CHILE**	% of imbalance respect to schedule - **SPAIN**
January	69.15%	7.24%
February	51.18%	8.11%
March	57.90%	8.85%
April	54.26%	9.03%
May	75.69%	8.19%
June	65.48%	9.94%
July	51.49%	7.67%
August	59.85%	10.65%
September	52.19%	12.41%
Octuber	49.04%	9.02%
November	42.65%	6.54%
December	53.21%	5.85%
AVERAGE 2014	**56.84%**	**8.62%**

Table 12: Comparative wind imbalance
Source: own production, data from [REE] & [CDEC SIC].

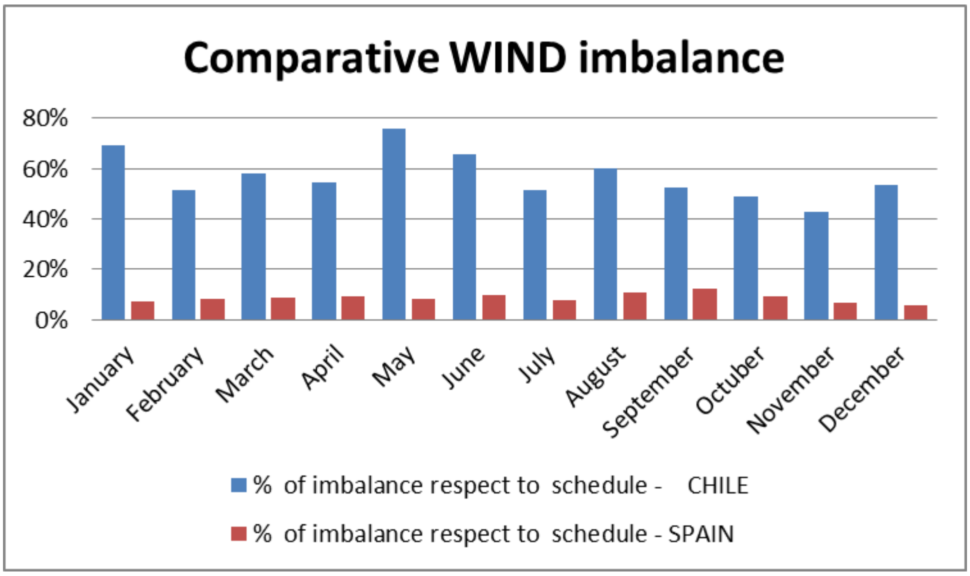

Figure 19: Comparative wind imbalance.
Source: own production, data from [REE] & [CDEC SIC].

In the case of the wind imbalance comparative it can be seen that the average imbalance for 2014 in Chile is more than six times higher than that of Spain.

The differences are especially large in the months of January and May because of the lack of schedule, already mentioned, and in the month in December because a low level of imbalance in Spain (5.9%). In these three months alone it can be realized how the imbalances differences grow in Chile up to more than nine times higher than in Spain.

SOLAR	% of imbalance respect to schedule - **CHILE**	% of imbalance respect to schedule - **SPAIN**
January	564.83%	17.41%
February	2259.42%	15.47%
March	2055.26%	9.52%
April	1849.02%	8.06%
May	24.00%	6.08%
June	15.63%	6.10%
July	14.41%	5.75%
August	15.42%	5.19%
September	18.73%	8.69%
Octuber	13.93%	9.37%
November	18.08%	14.66%
December	22.78%	13.20%
AVERAGE 2014	**572.63%**	**9.96%**

Table 13: Comparative solar imbalance
Source: own production, data from [REE] & [CDEC SIC].

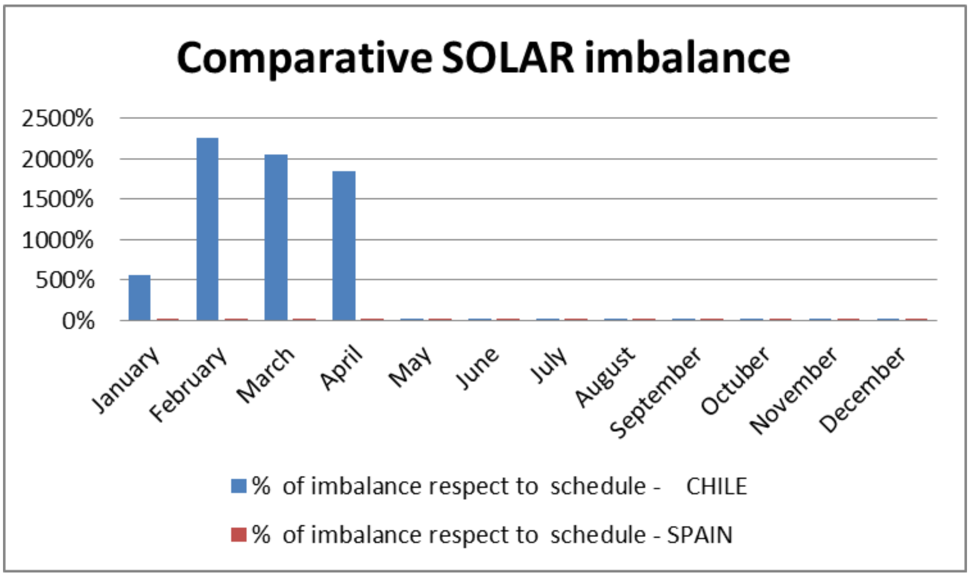

Figure 20: Comparative solar imbalance.
Source: own production, data from [REE] & [CDEC SIC].

Moreover, there was a huge difference between the Spanish solar average imbalance and the Chilean solar average imbalance, being the imbalance in Chile more than 57 times bigger.

This huge imbalance was mainly due to the levels registered in the first four months of 2014 when differences ranged from 500% to more than 2000%, being the generation more than 20 times greater than schedule in most of the cases.

Either way, leaving out the first four months, the average imbalance would be 17.9% in Chile which means that the imbalance will still be almost 8 points higher than in the reference system. There is no additional information that may allow us to forecast that such high imbalance will be reduced when new solar capacity comes on-line.

All that said, it may be concluded that some regulation is needed to incentive generation units to improve their scheduling performance, expecting imbalance reduction to achieve lesser imbalance ratios closer to the ones of a mature renewable system such as the one in Spain.

As means to carry out the present study three imbalance reduction possible targets are going to be set to estimate the potential saving for each case in the next chapter. The percentages of imbalance reduction are 50%, 25% and 10%.

This percentage could bring an annual reduction in the imbalance, in energy terms, in Chile as follow:

- The annual ***wind imbalance*** would be reduced in:
    - Target reduction of 50%: **183,860 MWh.**
    - Target reduction of 25%: **91,930 MWh.**
    - Target reduction of 10%: **36,772 MWh.**
- The annual ***photovoltaic imbalance*** would be reduced in:
    - Target reduction of 50%: **58,138 MWh.**
    - Target reduction of 25%: **29,069 MWh.**
    - Target reduction of 10%: **11,628 MWh.**

CHAPTER 4

REDUCTION IN IMBALANCE COST

Once the estimation of the possible reduction in imbalance is known, this section is going to approximate the amount of money which could be saved in case the reduction targets set in the previous chapter are achieved. By estimating how much money can be saved it can be better known how much would be worth to invest in the means needed to achieve the imbalance reduction target.

Firstly, the imbalance cost measured in dollars for 2014 by technology is going to be calculated. Later the imbalance reduction target will be multiplied by the cost of imbalance already computed in order to figure the amount of money that it can be saved with the imbalance reduction. This saving represents the money needed in case of managing inefficiently the system, in other words the cost of the ancillary services when a facility have to increase or decrease production to balance the system.

As the cost of imbalance per MWh is not public data in Chile there is no choice but to pick an alternative as estimation. For the purpose of estimating the cost of imbalance per MWh two scenarios with differences assumptions are going will be considered:

- Scenario 1: the relationship between the spot price and imbalance cost in Spain is going to be calculated and then the imbalance cost $/MWh in Chile is going to be approximated by applying the same relationship over the Marginal Cost of the reference bar for SIC subsystem (Quillota bar).
- Scenario 2: the cost of the positive and negative imbalance is going to be estimated by using data from the Chilean Market.

4.1 General methodology.

The formulas applied to assess the potential saving that could be achieved with the imbalance reduction levels, are going to be detailed along this section.

For the propose of calculating the **Hourly Cost by each technology in dollars for 2014,** it is needed first to compute the hourly Net imbalance in MWh by technology, as it is shown in (3) and secondly multiply it by the Upwards and Downward Imbalance Cost according to (4).

$$\text{Net imbalance }_{\text{h}}^{\text{tech}} = \sum_{\text{i}=1}^{\text{N}} \text{Generation}_{\text{h}}^{\text{tech,i}} - \text{Schedule}_{\text{h}}^{\text{tech,i}} \quad (\mathbf{3})$$

$$\text{Hourly Cost}_{\text{h}}^{\text{tech}} = \left\{ \begin{array}{l} \text{If Net imbalance }_{\text{h}}^{\text{tech}} > 0,\ \text{Net imbalance }_{\text{h}}^{\text{tech}} \cdot \text{Upwards Imbalance Cost} \\ \text{If Net imbalance }_{\text{h}}^{\text{tech}} < 0,\ \text{Net imbalance }_{\text{h}}^{\text{tech}} \cdot \text{Downwards Imbalance Cost} \end{array} \right\} \quad (\mathbf{4})$$

Where:

Upwards Imbalance Cost: is the unit cost paid by the facilities that have a positive Net imbalance (higher generation than schedule). As there is no public information about this cost, it would be estimated in two scenarios in sections 4.2 and 4.3.

Downwards Imbalance Cost: is the unit cost paid by the facilities that have a negative Net imbalance (lower generation than schedule). As there is no public information about this cost, it would be estimated in two scenarios in sections 4.2 and 4.3.

The **Total Cost by technology in dollars for 2014** is calculated by adding the Hourly Cost as it is stated in (5).

$$\text{Total Cost}^{\text{tech}} = \sum\nolimits_{\text{h}=1}^{\text{N}} \text{Hourly Cost}_{\text{h}}^{\text{tech}} \quad (\mathbf{5})$$

Finally, the Total Cost by technology in dollars, already calculated in (5), is divided by the Absolute Net imbalance of that technology, calculated as it is shown in (6), obtaining the unitary **Imbalance Cost 2014 by technology in dollars per Megawatt hour imbalanced (7)**:

$$\text{Absolute Net imbalance}^{\text{tech}} = \sum\nolimits_{\text{h}=1}^{\text{M}} \left| \text{Net imbalance }_{\text{h}}^{\text{tech}} \right| \quad \mathbf{(6)}$$

$$\text{Imbalance Cost 2014}^{\text{tech}} = \frac{\text{Total Cost}^{\text{tech}}}{\text{Absolute Net imbalance}^{\text{tech}}} \quad \mathbf{(7)}$$

Once having the cost, **potential saving by technology and target** could be obtained multiplying Absolute Net Imbalance by technology times Reduction Target times Imbalance Cost 2014 by technology as it is indicated in (8):

$$\text{Potential Saving}_{\text{target}}^{\text{tech}} = \text{Absolute Net Imbalance}^{\text{tech}} \cdot \text{Reduction Target} \cdot \text{Imbalance Cost 2014}^{\text{tech}} \quad (\mathbf{8})$$

Where:
Reduction Target is the percentage of reduction of the imbalance cost set in section 3.4.

The lack of information about Upwards and Downwards Imbalance Cost of the Chilean System, needed in equation (4), forced to estimate these costs to be able to compute the potential saving.

In the following sections, the estimations made in the two scenarios used in this regard are developed in detail.

4.2 Scenario 1: estimation of balancing cost using Spanish data.

Data from the Spanish power system has been used to estimate the imbalance cost for the Chilean market in 2014 in order to come up with the potential saving. .

First, the Spanish Upwards and Downwards imbalances cost by technology were computed by using the information published by the System Operator using data the data detailed in Annex 2 from [REE].

Note that for a certain hour, there is always only one imbalance for each technology that is because it is a net imbalance of all the units using that technology. This means, the hourly imbalance is the result of aggregating all the imbalances of the units of that technology, so for each hour there could have been both upwards and downward imbalances. Note that in the Spanish electricity Market the individual imbalances of each unit are not known because the actual production is considered confidential as opposed to the programs which are released by the operators. Additionally, from the point of view of the system operator a small imbalance of a single unit is not particularly important. The mean problems stem from the imbalances in the system, which may require the system operator to act.

In order to find the **Spanish Upwards and Downwards Unit Cost by technology in Euros per MWh imbalanced,** the Hourly Cost by technology in Euros, Total Cost by technology in Euros and Net imbalance by technology in MWh have to be computed as shows equation from (9) to(14) :

$$\text{Hourly Upwards Cost Spain}_h^{tech,+} = \text{Net Imbalance}_h^{tech} \cdot \text{Upwards Unit Cost Spain}_h, \text{if Net Imbalance}_h^{tech} > 0 \quad \textbf{(9)}$$

$$\text{Hourly Downwards Cost Spain}_h^{tech,-} = \left|\text{Net Imbalance}_h^{tech} \cdot \text{Downwards Unit Cost Spain}_h\right|, \text{if Net Imbalance}_h^{tech} < 0 \quad \textbf{(10)}$$

Where:

Upwards Unit Cost Spain$_h$: is the hourly cost paid by the facilities that have a positive imbalance in Spain. It was downloaded as it is detailed in Annex 2.

Downwards Unit Cost Spain$_h$: is the hourly cost paid by the facilities that have a negative imbalance in Spain. It was downloaded as it is detailed in Annex 2.

$$\text{Total Upwards Cost Spain}^{tech,+} = \sum_{h=1}^{N} \text{Hourly Upwards Cost Spain}_h^{tech,+} \quad \textbf{(11)}$$

$$\text{Total Downwards Cost Spain}^{tech,-} = \sum_{h=1}^{N} \text{Hourly Downwards Cost Spain}_h^{tech,-} \quad \textbf{(12)}$$

$$\text{Upwards Net Imbalance}^{\text{tech},+} = \sum_{h=1}^{N} \text{Net Imbalance}_h^{\text{tech}}, \text{if Net Imbalance}_h^{\text{tech}} > 0 \ (\mathbf{13})$$

$$\text{Downwards Net Imbalance}^{\text{tech},-} = \sum_{h=1}^{N} \text{Net Imbalance}_h^{\text{tech}}, \text{if Net Imbalance}_h^{\text{tech}} < 0 \ (\mathbf{14})$$

So we obtain the unit cost for both sides of the imbalance by each technology as it is stated (15) y (16)

$$\text{Upwards Unit Cost}^{\text{tech},+} = \frac{\text{Total Upwards Cost Spain}^{\text{tech},+}}{\text{Upwards Net Imbalance}^{\text{tech},+}} \ \textbf{(15)}$$

$$\text{Downwards Unit Cost}^{\text{tech},-} = \frac{\text{Total Downwards Cost Spain}^{\text{tech},-}}{\text{Downwards Net Imbalance}^{\text{tech},-}} \ \textbf{(16)}$$

All the unit costs are always measured in euros or dollars per imbalanced energy. There is another way of measuring the unit cost of the imbalance which is very common in the Spanish Electricity contracts, such as euros per generated energy. In this document it is used the first one because of the approach of the study, It is not necessary to know the loss of money per each unit of energy. I do want to know the relation between imbalances and costs under different regulatory systems.

Then, the **<u>relationship between the spot price and the imbalance cost by technology</u>** in the Spanish market is calculated according to (17) and (18):

$$\text{Upwards Ratio}^{\text{tech},+} = \frac{\text{Upwards Ratio}^{\text{tech},+}}{\overline{\text{Spanish Spot Price}}} \ \textbf{(17)}$$

$$\text{Upwards Ratio}^{\text{wind},+} = \mathbf{27}\%$$

$$\text{Upwards Ratio}^{\text{photovoltaic},+} = \mathbf{23}\%$$

$$\text{Downwards Ratio}^{\text{tech},-} = \frac{\text{Downwards Unit Cost}^{\text{tech},-}}{\overline{\text{Spanish Spot Price}}} \ \textbf{(18)}$$

$$\text{Downwards Ratio}^{\text{wind},-} = \mathbf{24}\%$$

$$\text{Downwards Ratio}^{\text{photovoltaic},-} = \mathbf{18}\%$$

Where:

$\overline{\text{Spanish Spot Price}}$: Is the average reference price for the Spanish electricity market. The hourly prices have been downloaded from the market operator website [OMIE].

Finally, the ratios of imbalance cost are applied to estimate the **<u>Unit Cost in Chile</u>** by applying them to the Marginal Cost of the reference bar (Quillota bar) using (19) and (20):

$$\text{Upwards Unit Cost Chile}^{\text{tech}} = \overline{\text{Quillota bar Marginal Cost}} \cdot \text{Upwards Ratio}^{\text{tech},+} \quad (\mathbf{19})$$

$$\text{Upwards Unit Cost Chile}^{\text{wind}} = \mathbf{35.90\ \$/MWh}$$

$$\text{Upwards Unit Cost Chile}^{\text{photovoltaic}} = \mathbf{30.50\ \$/MWh}$$

$$\text{Donwards Unit Cost Chile}^{\text{tech}} = \overline{\text{Quillota bar Marginal Cost}} \cdot \text{Downwards Ratio}^{\text{tech},-} (\mathbf{20})$$

$$\text{Donwards Unit Cost Chile}^{\text{wind}} = \mathbf{30.97\ \$/MWh}$$

$$\text{Donwards Unit Cost Chile}^{\text{wind}} = \mathbf{24.12\ \$/MWh}$$

Where:

$\overline{\text{Quillota bar Marginal Cost}}$: is the is the average Marginal cost for the reference bar (Quillota) published by CEDEC SIC in [CDEC SIG CM]

As soon as imbalance costs by technology have been estimated it is just needed to apply them to the methodology describe in section 4.1 in pursuance of finally getting the potential saving.

The outcome of the first scenario showed an average imbalance cost for 2014 of:

- Wind imbalance cost: **34.25 $/MWh**
- Photovoltaic imbalance cost: **29.73 $/MWh**

Such estimation turned out in the following final saving amount by percentage of imbalance reduction:

50% of imbalance reduction Target:

$$Wind\ Potential\ saving_{\ s1\_rt50} = \$\,\mathbf{6,297,836.94}$$

$$Solar\ Potential\ saving_{\ s1\_rt50} = \$\,\mathbf{1,728,594.13}$$

$$\boldsymbol{TOTAL\ SAVING_{s1\_rt50}} = \$\,\mathbf{8,026,431.07}$$

25% of imbalance reduction Target:

$$Wind\ Potential\ saving\ _{s1\_rt25} = \$\ \mathbf{3,148,918.47}$$

$$Solar\ Potential\ saving\ _{s1\_rt25} = \ \$\ \mathbf{864,297.07}$$

$$\boldsymbol{TOTAL\ SAVING_{s1\_rt25}} = \$\ \mathbf{4,013,215.54}$$

10% of imbalance reduction Target

$$Wind\ Potential\ saving\ _{s1\_rt10} = \$\ \mathbf{1,259,567.39}$$

$$Solar\ Potential\ saving\ _{s1\_rt10} = \ \$\ \mathbf{345,718.83}$$

$$\boldsymbol{TOTAL\ SAVING_{s1\_rt10}} = \$\ \mathbf{1,605,286.21}$$

4.3 Scenario 2: estimation of balancing cost throughout Chilean data analysis.

In this scenario the positive and negative imbalance price was estimated as follows:

Positive imbalance cost (when generation exceeds schedule):

The opportunity cost of the units that provide imbalance services has to be considered when estimating the imbalance cost. In order to get a value for the positive imbalance cost it was assumed that the benefit or opportunity cost is a 23% of the marginal costs. The marginal cost is the price that generation companies were receiving for generating. It may be inferred that a percentage of this price should be their net margin needed to reward its activity, once their operating and investment costs were fulfilled. This net margin was set at 23 % in the present study according to the information in the Annex 3.

The result is as follows:

$$\text{Upwards Imbalance Cost} = 23\% \cdot \overline{\text{Quillota bar Marginal Cost}} = 30.14\ \$/\text{MWh} \quad \textbf{(21)}$$

Negative imbalance cost (when generation is lower than schedule):

The cost of negative imbalance of the system was estimated as the average of the marginal cost for the most expensive hours (as we supposed that was the price for the units that usually provide such imbalance service) less the average marginal cost that would be the cost for the system in case of no imbalance.

In search of the average marginal cost for the most expensive hours, the marginal cost was ranked and the 50% more expensive hours were selected, that was the first 4,380 hours in the ranking.

Applying this premise the following results were obtained:

$$\text{Variable Cost}_{\text{EU}} = \overline{\text{Marginal Cost}_{\text{Eh}}} = 182.19\$/\text{MWh} \quad \textbf{(22)}$$

Where:

Variable Cost$_{EU}$: is the Variable Cost ($/MWh) for the more expensive units which are supposed to solve the negative imbalance.

Marginal Cost$_{Eh}$: is the Marginal Cost ($/MWh) for the more expensive 4,380 more expensive hours of the year.

$$\text{Upwards Imbalance Cost} = \text{Marginal Cost}_{\text{EU}} - \overline{\text{Quillota bar Marginal Cost}}$$
$$= 51.13 \text{ \$/MWh}$$

When imbalance costs have been estimated it is just needed to apply these cost in the methodology described in section 4.1 in pursuance of finally getting the potential saving.

The average imbalance costs per MWh by technology for 2014 were:

- Wind imbalance cost: **37.16 $/MWh**
- Photovoltaic imbalance cost: 3**2.65 $/MWh**

This means that the following savings could be reached according to the second scenario:

50% of imbalance reduction Target:

$$Wind\ Potential\ saving\ _{s1\_rt50} = \$\ \mathbf{6,831,907.67}$$

$$Solar\ Potential\ saving\ _{s1\_rt50} = \ \$\ \mathbf{1,898,347.90}$$

$$\boldsymbol{TOTAL\ SAVING_{s1\_rt50}} = \$\ \mathbf{8,730,255.57}$$

25% of imbalance reduction Target:

$$Wind\ Potential\ saving\ _{s1\_rt25} = \$\ \mathbf{3,415,953.83}$$

$$Solar\ Potential\ saving\ _{s1\_rt25} = \ \$\ \mathbf{949,173.95}$$

$$\boldsymbol{TOTAL\ SAVING_{s1\_rt25}} = \$\ \mathbf{4,365,127.78}$$

10% of imbalance reduction Target:

$$Wind\ Potential\ saving\ _{s1\_rt10} = \$\ \mathbf{1,366,381.53}$$

$$Solar\ Potential\ saving\ _{s1\_rt10} = \ \$\ \mathbf{379,669.58}$$

$$\boldsymbol{TOTAL\ SAVING_{s1\_rt10}} = \$\ \mathbf{1,746,051.11}$$

4.4 Results and conclusions of the chapter.

From our estimation the potential saving is not negligible, as in the lesser tough scenario (10% imbalance reduction target) more than one and a half million could be saved per year, being the maximum potential saving more than seven millions per year.

POTENTIAL SAVING PER YEAR	50% imbalance reduction	25% imbalance reduction	10% imbalance reduction
Scenario 1 - WIND	$ 6,297,836.94	$ 3,148,918.47	$ 1,259,567.39
Scenario 1 - FHOTOVOLTAIC	$ 1,728,594.13	$ 864,297.07	$ 345,718.83
SCENARIO 1	**$ 8,026,431.07**	**$ 4,013,215.54**	**$ 1,605,286.21**
Scenario 2 - WIND	$ 6,831,907.67	$ 3,415,953.83	$ 1,366,381.53
Scenario 2 - FHOTOVOLTAIC	$ 1,898,347.90	$ 949,173.95	$ 379,669.58
SCENARIO 2	**$ 8,730,255.57**	**$ 4,365,127.78**	**$ 1,746,051.11**

Table 14: Comparative wind imbalance.
Source: own production, data from [REE] & [CDEC SIC].

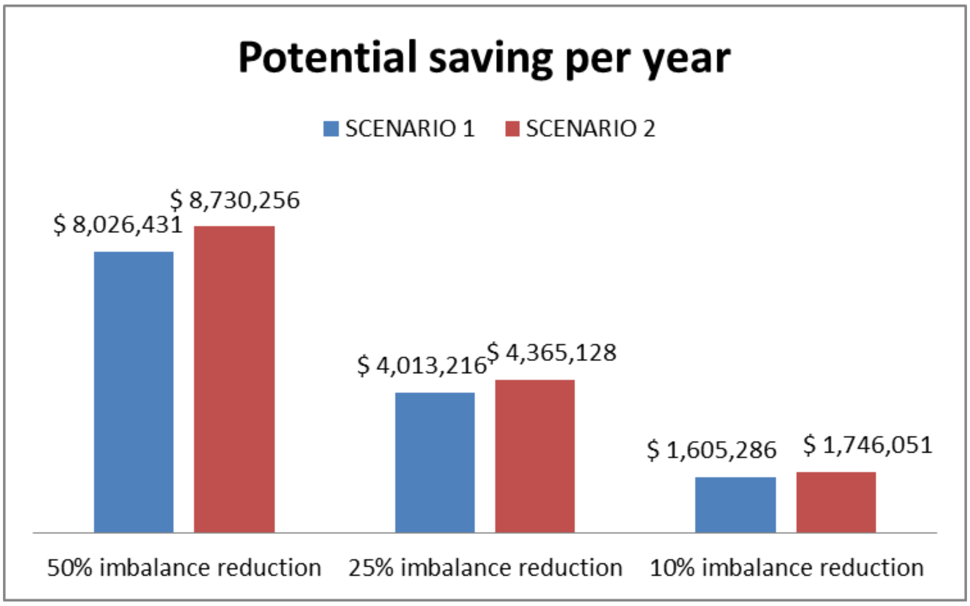

Figure 21: Comparative wind imbalance.
Source: own production, data from [REE] & [CDEC SIC].

Nevertheless, as we saw in the comparative with Spain, the reduction of 25% apparently is quite obtainable and this would mean a potential saving of at least more than four million dollars ,which it seems enough to start considering to implement some regulatory changes.

Beyond these numbers we have to bear in mind that a better management and integration of the renewable generation in the power system will allow more renewable capacity to be installed. Renewable capacity installation forecast in Spain has been growing as regulation obligations have become more demanding regarding wholesale market operations, imbalance cost allocation, real time information and flexibility request.

CHAPTER 5

RELEVANT ASPECTS FOR IMBALANCE REGULATION

As we have already seen it is important to have specific regulation as for to minimize imbalance levels. It is important to send signal to facilities in order to make them follow the schedule and invest resources to have good forecast system in order to be able to get a robust schedule.

In order to improve schedules it is important to give this responsibility to the generation units and to establish procedures that will push them towards a greater efficiency in managing forecasts and scheduling.

There is very interesting study [LDK, 2013] that LDK consultants develop for the European Union in order to get the most important points to have in mind in order to regulate Imbalance.

In the sections below it has been explained the most important aspects to bear in mind when setting the imbalance procedures according to the mentioned study.

5.1 Allocation of balancing costs.

When regulating imbalance the cost can be allocated to all users or just to the agents that are out of balance, so allocating the cost on the part that are causing the imbalances. Also, there is the option of mixing both possibilities.

In this regard, there are two models:

Gross Model: As the system operator is in charge of the system balancing, it should be firstly charge for the balancing costs (reserving capacity and purchasing Balancing Energy) which will be pass later to whom it may concern.

According to this model, as the grid users are benefiting from having access to a balance system they should pay for it in a uniform way throughout transmission tariffs for example.

Regardless of this, the Market Participant also have to pay for the energy imbalances as they are not comply with the obligation of being balanced following the schedule approve by the System Operator.

Net Model: This other model poses the alternative of paying the costs of balancing with the Imbalance Settlement, in other words the cost of the imbalance have to be paid by the agents who caused the problem.

Normally, under this approach, System uses to be long and finally system operator turns down generator and the Balancing Mechanism becomes a revenue producer. This usually happens in dual price systems, where there is a price for positive imbalance and another for negative imbalance.

The LDK Consultants study recommends the Gross Model recovering, in that way, the imbalance cost is recovered from both, the beneficiaries and the originators of the imbalance.

Also there is important to think of that the allocation method should have a double objective of:

- Reflect the cost of balancing actions.
- Incentive Market participant to keep the system balanced.

5.2 Imbalance price.

Usually, when marginal pricing is applied for balancing provider it is also used for remuneration of the corresponding services. But, if pay-as-bid is used to remunerate balancing providers, the imbalance price may be calculated as the average price.

There are different methods that can be applied in order to compute the average price:

- Weighted average of all offers accepted in the period resulting one price.
- Weighted average of all offers accepted in each direction resulting two prices, one per direction.
- Weighted average of the bid accepted in the direction of the system imbalance resulting one price.
- Two prices are computed, reverse and main price. The reverse price is computed as a proxy market price and the main price is the average of balancing energy costs in the direction of the system imbalance.

Dual pricing delivers strong incentives but it also has some strong drawbacks:

- Imbalance price based on accepted offers are not distributed symmetrically. Some offers are from units that are already recovered their fixed costs but others need to still recover their fixed costs as they mainly performance on balancing services. If imbalance prices are based on accepted bids this asymmetry tends to result in agents entering long and then producing a knock on the cost that is assumed by the consumers.
- When there are two prices, one for each direction of the imbalance, the risk in case of error is greater and then the cost increase as the risk is bigger.
- The system usually over or under recover costs when dual imbalance price is used (see section 5.9).

On the other hand, single prices are a good option in terms of simplicity, transparency, easier to understand and justified. But, it also has some problems as it depends upon the direction of the system imbalance and then mistakes on the calculation can lead to big changes in the settlement process.

Also, it is important to consider a reservation fee in order to have a correct incentive because if there is no capacity fee in the imbalance prices, then units are not going to be motivated to be balanced when there is an energy/capacity price in the wholesale market.

It seems that a single price set by the accepted bids in the direction of the system imbalance seems to be a good option to start with, as it is simpler but it is probably better to change to marginal price in the direction of the system in the long term.

5.3 Monitoring imbalance settlements.

It is important a good monitoring system for detecting poor performance of the imbalance mechanism or any abuse from the market agents.

The national regulatory authority has to receive from the system operator the information detailed below to analyse it and detect any irregularity:

- Imbalance price per period.
- Imbalance cost assumed by each market agent.
- Imbalance volumes per unit.
- Imbalance volumes and costs for renewable units.
- Surplus or deficit in imbalances settlement.
- Change on the merit order list motivated by network congestions.

It is also relevant to invest on resources to guarantee a high level of confidentiality. In this sense, technical (secure and dependable software) and organizational (restricted staff) measures have to be established.

5.4 Imbalance settlements.

There should be some clear objectives in every market such as the improvement on competition, cost reduction and the integration of renewable capacity if we want to remain competitive while reinforcing environmental sustainability.

It is necessary to have a simple, transparent and low risk settlements procedure to get this triple objective.

5.4.1 Complexity

The Net Model imbalance price calculation is simpler than Gross Model but it has some problems with transparency. In the Net approach, costs and revenues are aggregated in a unique process and the net result will be settled, so it is difficult follow and explain imbalance price evolution.

On the other hand Gross Model is more complex as it is composed for a large number of counteracting cash flows but it is easier to understand price development.

In conclusion, it is better to use a Gross Model because of transparent issues.

5.4.2 Risk

New entrants and small companies may be troubled in markets where there is a system that significantly increase the risk of payment defaults that have to be bearded among the participants. Credit risk reduces the motivation of the agent to participate in future periods in the market and in some cases it put them out of the market.

One way to solve or reduce this risk is to share the unpaid debt amongst all the users instead of just sharing it between the companies participating in a market in a certain period.

Anyway, the most effective way to handle this problem is throughout credit cover in form of bank guarantees, so it is important to make an effort in order to establish a strong system in this sense.

Great care should be taken on the following aspect to get good results:

- It should be clear how potential indebtedness will be computed.

- It should be taken into account agent trading behaviour, timing of settlement activities, level of imbalance and prices and balance of risk between parties.
- Methodology complexity as it would be difficult to operate if it is extremely complex.
- It has to be defined when additional security would be required.

5.4.3 Cashflow

It is difficult to be managed for small and medium size participant the delays on financial settlement for long period. It can be attenuated by aligning the time of settlement an in this way tax exposure will be also minimise.

When Balancing Service Provision and imbalance settlement are performed in the same day some cashflows would be offset. But this netting effect should not be a reason to delay the settlement process for long time because financial issues could reduce the positive effect.

Additionally, it should be born in mind that payments have to be received before debs are being paid to reduce the risk exposure of the central counterparty.

5.5 Imbalance settlement surplus regulation.

The quantity of imbalance collection surplus or deficit will depend on the imbalance settlement methodology. It should be as low as possible in order to avoid market distortions.

The imbalance differences are caused by mismatches in the settlement process described below.

1. Usually reservation fees will have been recovered in different settlement periods regardless of the activation of energy. Some models recover reservation fees through transmission charges. When the imbalance prices have a portion of reservation fee then, this fee will be, in these cases, double count.
2. When different methodologies are used for balancing energy and energy imbalance will lead on deficits or surpluses, for example if pay-as-bid methodology is used for balancing mechanism and marginal pricing for imbalance.
3. Dual imbalance pricing mechanisms also generate surplus and deficit even when the system is balanced. There are always some agents out of balance, even though they imbalances may net out, and the spread between imbalance prices for short and long position will produce revenue.
4. Rounding issues and the exclusion of some balancing actions will also lead on deficit or surpluses.
5. Sometimes the difference between prices, pay-as-bid in balancing mechanism and average pricing for imbalance, can motivate under deliver.
6. Compensation Program to pay the unintentional deviation could incentive units to be out of balance.

When the cause of the surplus or deficit is identified then a solution can be determined as follow:

- Case 1: surplus should be invested on reducing the transition charging.
- Cases 2-4: surpluses, in these cases, come from the imbalances agents and they can be given to the balance units as it can be a way to incentive units to be on balance. It is not always possible because it is quite difficult sometimes to exactly comply with the schedule. Then, Surpluses can also be given back to every agent according to the metered volumes or taking in to account how close units are from their schedules.

- Case 5: if the imbalance price is lower than the accepted offer price or is bigger than the accepted bid price there is an incentive to be out of balance for the agent. Then, it is required a penalty that motivate unit to be balanced.
- Case 6: in order to reduce the surplus or deficit motivated by the Compensation Program the implicit balancing should also be penalize.

In short, firstly the reasons for the surpluses or deficits in the system have to be identified. Then, these differences have to be reduced adapting the process. And finally, the returns of the surpluses or deficit have to be compensated to the parts that create then in general.

In some cases, surpluses can also be used to motivate participant to be balanced. The returns should be distributed according to the size or taking in to account good behaviours.

CHAPTER 6

CONCLUSIONS

6.1 Conclusions

The main objective of the thesis was to find the most important aspects to manage efficiently the imbalance between generation and schedule in an electric system.

In order to get this information, the Chilean System, where there is no imbalance regulation at all and where renewables are increasingly relevant, has been analyzed. The study was basically focus on renewable, namely wind and photovoltaic technologies, because these are the most representative technologies imbalance cost-wise.

It is concluded that the level of imbalance in Chile is significantly high when compared to the Spanish market, with a more mature renewable sector and with imbalance regulation.

After the analysis, it is possible to affirm that, in part, the high level of imbalance in Chile was caused for a lack of motivation of the agents to keep in balance and a bad schedule forecast.

The electric system imbalances of both systems are as follows:

- Percentage of imbalance respect to schedule - SPAIN
    - Wind percentage for 2014: 8.6 %
    - Photovoltaic percentage for 2014: 10%
- Percentage of imbalance respect to schedule – CHILE
    - Wind percentage for 2014: 56.8 %
    - Photovoltaic percentage for 2014: 572.6 %

We has estimated a potential saving in energy term between more than 48,000 to almost 242,000 MWh depending on the imbalance reduction targets (50%, 25% and 10%).

It has been calculated the saving that could be achieved in monetary terms with the reduction of the imbalance in three imbalance reduction targets. The potential savings could range from $ 670,000 per year in the low scenario, with an imbalance reduction of 10%, and 7.8 million dollars per year in the high case, with an imbalance reduction of 50%.

Finally we have gone through an analysis of the most important features to take into account in order to send a signal to installations to make then follow the schedule and, in that way, be more efficient with regard to imbalance levels.

In this regard, it is very important:

- Allocation of balancing cost: this cost should reflect the cost of the balancing actions and incentivize participant to keep the system balance.
- Imbalance price: it is recommended to start with a simple system (single price set by accepted bids in the direction of the system imbalance) and move to a more complex method such as marginal pricing.
- Monitoring system: to detect bad performance of the imbalance system or any abuse from market agent and then be able to make the necessary actions to solve these problems.
- Imbalance settlement: there should be a triple objective in every market: improvement on competition, cost reduction and renewable integration. In order to get this triple objective it is necessary that imbalance settlement have some attribute such as simplicity, low risk and transparency.
- Settlement surpluses: they should be managed in a good way and to do so, the origin of surpluses should be identified in order to reduce then adapting processes. The surpluses already generated should be returned to the parts that create them.

Finally it could be affirmed after the analysis that it is important to have imbalance regulation in order to reduce avoidable cost. In the case of Chile, as we have seen in the comparison with Spain, there is a big room for improvement.

6.2 Limitations

The main limitation that it has been found is the lack of information to carry out the calculation of the imbalance cost.

Firstly, when it was intended to compute the imbalance in energy terms for the two major systems in Chile, Northern Interconnected System (SING) and Central Interconnected System (SIC), there was a problem with the hourly data of SING as it was not robust enough. As a result, it was only possible to do a deep analyses for the SIC system.

Then, when the potential saving for the possible imbalance reduction targets were figured there was not public data about the imbalance cost, so we made some estimations.

6.3 Further research

As in this approximation it has been concluded that it could be save relevant quantities of money with imbalance reduction in the case of Chile, it is considered that is should be very interesting to make the same analyses but with real cost information and made it for all the system in the country as it was impossible in this case because of lack of robust data.

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ANNEXES

ANNEX 1. EXCEL MACRO CODE

```
Dim wbOrigenProgramacion As Workbook

Dim wbOrigenOperacion As Workbook

Dim sheetResultados As Excel.Worksheet

Dim sheetProgramacion As Excel.Worksheet

Dim sheetOperacion As Excel.Worksheet

Dim fecha As String

Dim filaResultados As Integer

Sub ResultadosMensual()

Dim mesStr As String

Dim mes As Integer

Dim diaStr As String

filaResultados = 1

rutaProgramacion = Workbooks("Resultados.xlsm").Sheets("Hoja1").Range("B1").Value

rutaOperacion = Workbooks("Resultados.xlsm").Sheets("Hoja1").Range("B2").Value

mes = Workbooks("Resultados.xlsm").Sheets("Hoja1").Range("B3").Value

If (mes < 10) Then

   mesStr = "0" + CStr(mes)

Else

   mesStr = CStr(mes)

End If

año = Workbooks("Resultados.xlsm").Sheets("Hoja1").Range("B4").Value

If (mes = 1 Or mes = 3 Or mes = 5 Or mes = 7 Or mes = 8 Or mes = 10 Or mes = 12) Then

   numeroDiasMes = 31

ElseIf (mes = 4 Or mes = 6 Or mes = 9 Or mes = 11) Then

   numeroDiasMes = 30

Else
```

```
  numeroDiasMes = 28
End If

For dia = 1 To numeroDiasMes
  If (dia < 10) Then
    diaStr = "0" + CStr(dia)
  Else
    diaStr = CStr(dia)
  End If
  archivoResultado = rutaProgramacion + "Resultado" + Right(año, 2) + mesStr + diaStr + ".xls"
  archivoProgramacion = rutaProgramacion + "PR" + Right(año, 2) + mesStr + diaStr + ".xls"
  archivoOperacion = rutaOperacion + "OP" + Right(año, 2) + mesStr + diaStr + ".xls"
  Call Resultados(archivoProgramacion, archivoOperacion, archivoResultado)

Next dia
ThisWorkbook.SaveAs Filename:=rutaProgramacion + "Resultado" + Right(año, 2) + mesStr
Set wbResultados = Workbooks.Open("c:\Resultados.xlsm")
wbResultados.Sheets("Hoja2").Cells.Clear
wbResultados.Save
ThisWorkbook.Close
End Sub

Sub Resultados(ByVal archivoProgramacion As String, ByVal archivoOperacion As String, ByVal
archivoResultados As String)
Dim prueba As String
Set wbOrigenProgramacion = Workbooks.Open(archivoProgramacion)
Set wbOrigenOperacion = Workbooks.Open(archivoOperacion)
ThisWorkbook.Activate
```

```
Set sheetResultados = ThisWorkbook.Sheets("Hoja2")

Set sheetProgramacion = wbOrigenProgramacion.Sheets("Hoja1")

Set sheetOperacion = wbOrigenOperacion.Sheets("gen_real")

' Escribimos la cabecera fija de los resultados

sheetResultados.Cells(1, 1).Value = "DIA"

sheetResultados.Cells(1, 2).Value = "HORA"

sheetResultados.Cells(1, 3).Value = "unidad MED"

sheetResultados.Cells(1, 4).Value = "MEDIDA"

sheetResultados.Cells(1, 5).Value = "unidad PRO"

sheetResultados.Cells(1, 6).Value = "PROGRAMA"

sheetResultados.Cells(1, 7).Value = "DESVIO"

sheetResultados.Cells(1, 8).Value = "TECNOLOGIA"

' Sacamos la fecha actual en funcion del nombre de archivo de programacion

fecha = Mid(Right(archivoProgramacion, 12), 5, 2) & "/" & Mid(Right(archivoProgramacion,
12), 7, 2) & "/20" & Mid(Right(archivoProgramacion, 12), 3, 2)


Call SacarDatos("Eólica Canela 1", "CANELA", "EOLICA")

Call SacarDatos("Eólica Canela 2", "CANELA 2", "EOLICA")

Call SacarDatos("Eólica Lebu", "LEBU (EOLICA)", "EOLICA")

Call SacarDatos("Eólica Totoral", "EL TOTORAL (EOLICA)", "EOLICA")

Call SacarDatos("Eólica Monte Redondo", "MONTE REDONDO", "EOLICA")

Call SacarDatos("Eólica Ucuquer", "UCUQUER", "EOLICA")

Call SacarDatos("Eólica Ucuquer 2", "UCUQUER_2", "EOLICA")

Call SacarDatos("Eólica Talinay", "TALINAY", "EOLICA")

Call SacarDatos("Eólica Punta Colorada", "PUNTA COLORADA (EOLICA)", "EOLICA")

Call SacarDatos("Eólica Cuel", "CUEL", "EOLICA")

Call SacarDatos("Eólica El Arrayán", " EL ARRAYAN", "EOLICA")

Call SacarDatos("Eólica San Pedro", " SAN PEDRO", "EOLICA")
```

```
Call SacarDatos("Eólica Los Cururos ", "LOS CURUROS", "EOLICA")

Call SacarDatos("Eólica Punta Palmeras ", "PUNTA PALMERAS", "EOLICA")

Call SacarDatos("Eólica Taltal", "", "EOLICA")

Call SacarDatos("Solar Tambo Real", "TAMBO REAL", "FOTOVOLTAICA")

Call SacarDatos("Solar SDGx01", "SDGx01 (Andacollo)", "FOTOVOLTAICA")

Call SacarDatos("Solar Esperanza", "ESPERANZA (SOLAR)", "FOTOVOLTAICA")

Call SacarDatos("Solar Llano de Llampos", "LLANO DE LLAMPOS", "FOTOVOLTAICA")

Call SacarDatos("Solar San Andrés", "SAN ANDRES (SOLAR)", "FOTOVOLTAICA")

Call SacarDatos("Solar Santa Cecilia", "SANTA CECILIA (EX - AVENIR)", "FOTOVOLTAICA")

Call SacarDatos("Solar Techos de Altamira", "", "FOTOVOLTAICA")

Call SacarDatos("Solar Diego de Almagro", "", "FOTOVOLTAICA")

Call SacarDatos("Solar PSF Pama", "PAMA", "FOTOVOLTAICA")

Call SacarDatos("Solar PSF Lomas Coloradas", "LOMAS COLORADAS", "FOTOVOLTAICA")

Call SacarDatos("Solar Las Terrazas", "", "FOTOVOLTAICA")

Call SacarDatos("Solar PV Salvador", "", "FOTOVOLTAICA")


ThisWorkbook.Save

wbOrigenProgramacion.Close

wbOrigenOperacion.Close

End Sub

 Sub SacarDatos(ByVal nombreOperacion As String, ByVal nombreProgramacion As String,
ByVal tipo As String)

 Dim UltLineaOperacion As Long

 Dim primerResultado As Integer

 Dim segundoResultado As Integer

UltLineaOperacion = sheetOperacion.Columns(2).Find("*", , , , xlByColumns, xlPrevious).Row

 Dim UltLineaProgramacion As Long
```

```
 UltLineaProgramacion = sheetProgramacion.Columns(1).Find("*", , , , xlByColumns,
xlPrevious).Row

   For i = 1 To UltLineaOperacion

      If (sheetOperacion.Cells(i, 2).Value = nombreOperacion) Then

         For j = 1 To UltLineaProgramacion

            If (sheetProgramacion.Cells(j, 1).Value = nombreProgramacion) Then

               For hora = 1 To 24

                  sheetResultados.Cells(filaResultados + hora, 1).Value = fecha

                  sheetResultados.Cells(filaResultados + hora, 2).Value = hora

                  sheetResultados.Cells(filaResultados + hora, 3).Value = nombreOperacion

                  sheetResultados.Cells(filaResultados + hora, 4).Value = sheetOperacion.Cells(i, 2
+ hora).Value

                  sheetResultados.Cells(filaResultados + hora, 5).Value = nombreProgramacion

                  sheetResultados.Cells(filaResultados + hora, 6).Value =
sheetProgramacion.Cells(j, 1 + hora).Value

                  primerResultado = 0

                  segundoResultado = 0

                  If (IsNumeric(sheetResultados.Cells(filaResultados + hora, 4).Value)) Then

                     primerResultado = sheetResultados.Cells(filaResultados + hora, 4).Value

                  End If

                  If (IsNumeric(sheetResultados.Cells(filaResultados + hora, 6).Value)) Then

                     segundoResultado = sheetResultados.Cells(filaResultados + hora, 6).Value

                  End If


                  sheetResultados.Cells(filaResultados + hora, 7).Value = primerResultado -
segundoResultado

                  sheetResultados.Cells(filaResultados + hora, 8).Value = tipo

               Next hora

               filaResultados = filaResultados + 24
```

```
          Exit Sub
        End If
      Next j
    End If
  Next i
End Sub
```

ANNEX 2. DATA DOWNLOADED FROM REE

In order to be able to make the imbalance comparative between Chilean and Spanish market in energy terms (section 3.3) and make the estimation of balancing cost in the first scenario (section 4.2) it has been necessary to use data from the section Publications → Settlement → SO monthly settlements of [REE].

There were downloaded the files listed below to have the Spanish imbalance data:

- C6_liquicomun_201401.zip
- C5_liquicomun_201402.zip
- C5_liquicomun_201403.zip
- C5_liquicomun_201404.zip
- C5_liquicomun_201405.zip
- C4_liquicomun_201406.zip
- C4_liquicomun_201407.zip
- C4_liquicomun_201408.zip
- C3_liquicomun_201409.zip
- C3_liquicomun_201410.zip
- C3_liquicomun_201411.zip
- C3_liquicomun_201412.zip

These files contain the public information about the System Operator settlements.

They have a pdf file called liquicom which has the information of average cost of the renewable imbalance by technology such as it is shown in Figure 22. This information has been used in section 3.3.

Coste medio de los desvíos de la energía renovable, cogeneración y residuos
Marzo 2014 C5

Tecnología (*)	Programa MWh	Desvíos netos horarios absolutos MWh	Producción medida liquidada total MWh	Producción medida liquidada exenta coste desvíos %	Desvío sobre programa %	Coste de los desvíos EUR	Coste de los desvíos EUR/MWh producido
Eólica	4.878.096,2	431.555,257	5.050.331,453	0,000	8,8	4.974.478	0,98
Fotovoltaica	699.283,9	66.603,222	697.630,000	2,852	9,5	917.273	1,31
Hidráulica	751.083,9	57.070,611	806.132,507	0,001	7,6	315.880	0,39
Térmica no renovable	1.636.916,7	35.230,345	1.627.582,357	0,002	2,2	345.613	0,21
Térmica renovable	355.557,8	22.782,908	365.401,012		6,4	142.525	0,39
Termosolar	398.306,0	78.261,960	385.175,316		19,6	834.214	2,17

Figure 22: Spanish imbalance data, example for March 2014.
Source: [REE].

Furthermore, they have hourly information about the imbalance in energy terms that was useful in the estimations of scenario 1. In particular, the following txt files were used:

- endmreeo: hourly imbalance of wind (MWh imbalanced)
- grpresol: hourly imbalance of photovoltaic (MWh imbalanced)
- codsvbaj and codsvsub: Upwards and Downwards Unit Cost Spain (€/MWh imbalanced)

ANNEX 3. NET MARGIN FOR CHILIAN GENERATION COMPANIES

According to [Generadoras, 2014], there are 12 generation companies in the two major Chilean systems which are listed in Table 2.

But, some of them are in the same business group thus there are five groups of companies listed below:

1. Colbún.
2. Endesa Chile: Pehuenche and Celta (Compañía Eléctrica Tarapacá S.A.) are also included in this business group.
3. AES Gener: Sociedad Eléctrica de Santiago, Angamos and Norgener are also included in this business group.
4. Guacolda.
5. San Isidro (Energis).
6. E.CL: Andina (Central Térmica Andina, S.A.) is also included in this business group.

In order to know the net margin the annual report for these companies have been checked and relation between operational revenues and net incomes has been computed giving as a result an average of 23 %.

In Figure 23 can be seen the percentage per business group:

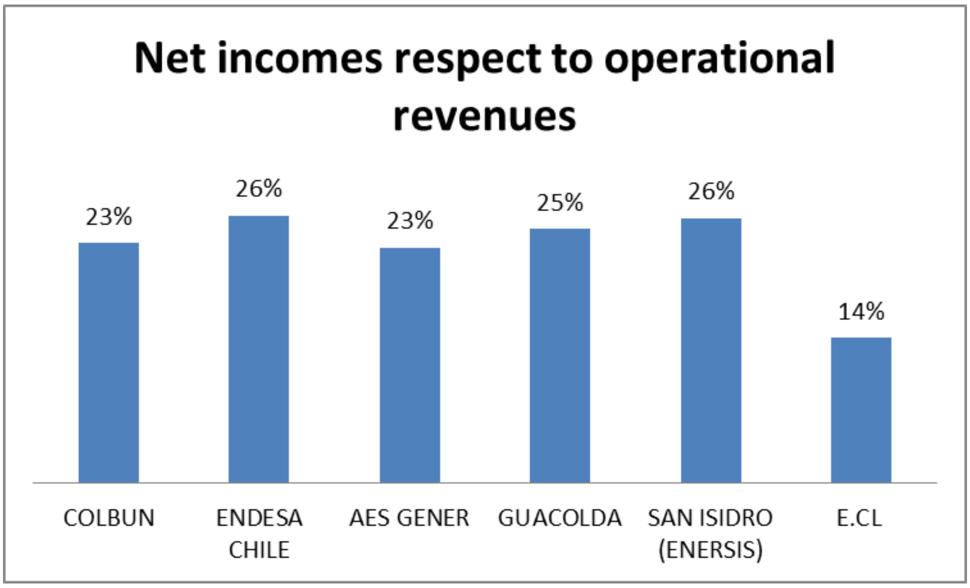

Figure 23: Percentage of net incomes respect to operational revenues.
Source: [COLBUN, 2015], [ENDESA 2015], [AES, 2015], [GUACOLDA, 2014], [ENERSIS, 2015] and [E.CL, 2015]